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Research article

External stakeholder risk response strategies selection in project portfolio

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ABSTRACT

To improve the effectiveness of external stakeholder risks (ESRs) management in project portfolios (PPs), a portfolio-wide risk response approach is required. However, current research is inadequate to effectively identify response strategies for ESRs, which brings challenges to managing ESRs in PPs. In this context, the purpose of this study is to select an appropriate combination of response strategies for ESRs by considering interactions among ESRs, projects, and response strategies in the PP. A Bayesian influence diagram (BID) coupled with a multi-objective optimization model is deemed suitable for this context. Firstly, a probability-sensitivity matrix is established to determine the key ESRs. Then, a BID is constructed to calculate the expected values of different combinations of response strategies. Finally, integrating stakeholder satisfaction and strategy cost, an optimization model for risk response strategy selection is established to obtain candidate combinations. By combining expected values and candidate combinations, the optimal strategy combination is selected. The proposed model comprehensively considers and evaluates the interactions between risks, projects, and risk responses. This enhances the desirability of expected outcomes and reduces project execution costs.

1. Introduction

Project portfolios (PPs) refer to a collection of projects, programs, sub-portfolios, and operations managed as a group to achieve strategic objectives. Their successful implementation is closely linked to various stakeholders, including customers, suppliers, and others involved [1]. Conflicts arising from divergent interests and aims of stakeholders often result in stakeholder risks during the implementation of PPs [2]. Among that, external stakeholder (such as governments, suppliers, and financial organizations) risks (ESRs) are more untameable than internal counterparts as their indirectness to PP managers. These ESRs have caused significant losses at various stages of PP [3], and managing ESRs is an essential aspect of achieving project portfolio management (PPM) objectives [4]. Any PPM approach that neglects ESRs may result in an unbalanced PP, highlighting the important role of managing these risks in PP [5]. ESR management is a part of risk management, including risk identification, assessment and response [1]. Its main purpose is to reduce the probability and/or the effect of events that are disadvantageous to the value, strategic fitness, and balance of the PP [6,7]. All three processes of ESR management are indispensable. The first two processes are extensively researched, while the ESR response has received limited attention. After identifying and assessing ESRs, organizations cannot be prepared for the future without dealing with risks [8]. ESR response, as the final step in ESR management, is centered around a targeted response strategy to the results of the

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previous assessment. However, most risk management practices focus on ESR identification and assessment, often overlooking ESR response. It is not conducive to reducing the likelihood and impact of negative outcomes and is therefore necessary to select an appropriate combination of response strategies for ESRs. By implementing effective risk response strategies, organizations can safeguard their key values and minimize the potential for harm [9]. Hence, paying attention to ESR response is of great significance to the success of PP.

ESR response aims to select appropriate response strategies according to the management ability of the organization [10,11]. When treating ESRs in PPs, the consideration of interaction effects is inevitable. There are several interactions to be considered. First, interactions of ERSs due to stakeholder relationships would influence risk responses [12]. Paying more attention to the interactions between risks can increase the expected response effects and lower execution costs. Second, no projects in PP are islands inside an organization [13,14]. ESRs in PP may come from common risk drivers, but they could also stem from the dependency between projects (e.g., competition among scarce resources, input-output relationships between projects, and bilateral information needs between two projects). Teller, Kock et al. [8] stressed the importance of considering PP dependency to make reasonable informed measures. Third, the selection of related response strategies can affect strategies' influence on the project objectives. These interaction effects manifest as positive or negative synergism of response strategies. Previous studies have neglected the interaction and the synergistic effect of risk response strategies [15,16], while the effect is unavoidable in reality.

The majority of researchers focusing on risk management have noticed the importance of risk response strategy selection (RRSS) [17–19]. Wu, Zhu et al. [17] pointed out that most previous research takes the risk exposure value as the control objective of risk response. However, except risk exposure value, there are many constraints, such as stakeholder satisfaction, time and funds in ESRs response, that also need to be considered [18]. The pursuit of the optimization of every objective brings a multi-objective model for the RRSS issue. In addition, with a constrained budget, it is impossible to control all ESRs, but only to take a limited response strategy to control key risks [20].

In summary, this study attempts to answer the following research question: ***How can an optimal combination of ESR response strategies be selected considering PP interaction?***

The methods applied to RRSS mainly include the optimization-based method [12], the work breakdown structure-based method [21], and the trade-off method [22], etc. These conventional research methods provide valuable theoretical insights into the RRSS. However, some of these ignore the correlations between variables during the implementation of PP, and the other methods fail to consider multiple criteria simultaneously when obtaining the optimal risk response strategy combination. To overcome these drawbacks, this study aims to present a method to select an appropriate combination of response strategies for ESRs based on Bayesian influence diagram (BID) and multi-objective optimization model. For one thing, the optimization model is used to analyze the multiple objectives for RRSS. For another, the BID model is suitable for modelling the interactive environment since it is a visualization tool and presents the interaction between various factors more intuitively [23]. The combination of them benefits enhancing multi-objective and variable interaction modelling. Therefore, the optimization-BID model evaluation method is constructed in this study for RRSS.

This study makes a dual contribution. First, it delves into ESR response, a crucial theme that has received limited research attention. Second, the present study introduces a novel RRSS model aimed at determining the most effective combination of ESR response strategies. By offering a more quantitative approach to selecting risk response strategies in project portfolio risk management, this research represents a significant step forward. The insights provided are valuable for managers striving to improve PP performance, ultimately promoting the success of PP.

In this study, RRSS for ESRs of PP is studied by propose a optimization-BID model evaluation method. The processes starts with identifying the key ESRs and related response strategies to ESRs. Second, by analyzing the interactions among ESRs, projects, and response strategies, the BID model, which can calculate the expected value of each response strategy combination, is constructed. Finally, the multi-objective optimization model is proposed using the cost and stakeholder satisfaction as control objectives. Based on the organizational requirements, the optimal response strategy combination is selected by the results of the optimization-BID model evaluation method. The rest of the paper is organized as follows. Section 2 introduces a literature review, and Section 3 proposes an RRSS decision model for ESRs. Section 4 provides an illustrative example. Section 5 discusses the theoretical and managerial implications, along with future directions for research. Finally, the study ends by answering the proposed research question.

2. Literature review

2.1. Research on stakeholder risk management

The term "stakeholder" was first introduced and utilized by the Stanford Research Institute in 1963 [24], leading to increasing recognition of the influence of stakeholders on organizational success and subsequently fostering the advancement of stakeholder-related research [25]. As defined by PMI [1], stakeholders refer to individuals, groups, or organizations that could be impacted, or perceive themselves to be impacted, by project decisions, activities, or outcomes. The existing literature has widely acknowledged the benefits of stakeholder risk management [26], which positively influences the success, balance and strategic alignment of PP. Hence, researching stakeholders and managing their associated risks represents a crucial and indispensable step in the execution of a project. Currently, many researchers have studied stakeholder risk [27] from the perspectives of a single project and PP.

At a single-project level, Xue, Shen et al. [28] established a network-based framework to analyze the dynamics of stakeholder conflicts and provided management strategies by detecting key conflicts and affected relationships among stakeholders. Wang, Gao et al. [29] developed a multi-tiered stakeholder risk network structure to propose targeted risk intervention strategies. Additionally, Xia, Zhong et al. [30] enhanced traditional risk assessment methods by incorporating a comprehensive evaluation of risk attributes and stakeholder influences on a project. However, these studies primarily focus on the analysis of single projects, neglecting the interaction relationships that in a nonlinear, complex, and interrelated setting, diverse components of a PP, including projects, stakeholders, and risks, exhibit relationships, such as interdependence, interaction and synergy may be formed [31], which potentially influencing stakeholder risk management. Hence, there is a necessity to research stakeholder risk management in the PP domain.

At the PP level, researchers have predominantly conducted relevant studies on PP risks concerning regulatory frameworks, management approaches, and characteristics of PP [32]. However, there exists a noticeable gap in research regarding the influence of PP stakeholders on risk management. As suggested by Xia, Zhong et al. [30] and other scholars, the involvement of stakeholders not only affects the efficiency of managing existing risks in PP but also has the potential to introduce additional risks. Therefore, stakeholder risk management holds a significant importance in PP risk management. Yet, the majority of studies have overlooked this aspect. In a limited number of stakeholder risk studies within PP, Guan and Guo [33] quantified the conflict risks between stakeholders. While their work contributed to advancing research on PP stakeholder risk, it is essential to highlight that their focus was primarily on internal risks. With the strategic perspective of PP management demanding a stronger external orientation within organizations [1], external stakeholders should also be taken into consideration.

Regarding ESR assessment, Bai, Kang et al. [27] constructed a Bayesian network (BN) model by considering risk interaction and project dependency. Although they considered stakeholder risk assessment in PP, the risk management process is inadequate without considering risk responses [34]. To date, there has been no prior exploration of ESRs in PP risk management, underscoring a significant research void that motivates the central theme of this study. Therefore, this study addresses the incorporation of ESRs in risk management, thereby broadening the research scope of PP risk management.

2.2. *Methods for the selection of risk response strategies*

Risk response constitutes a crucial phase in risk management, entailing the evaluation of identified risks and the implementation of suitable measures to address or mitigate them [1]. In project management or PPM, risk response typically involves developing plans to mitigate the impact of risks, transferring risks, accepting risks, or taking actions to reduce the likelihood of risk occurrence. Effective risk response empowers project or PP teams to adeptly navigate risks, thereby ensuring the achievement of their objectives. Consequently, there has been a burgeoning interest in exploring risk response methodologies [12].

In the existing literature, prominent methods utilized for determining risk response strategies in project or PP risk management include the zonal-based approach, traditional methods such as the trade-off method, the work breakdown structure (WBS)-based method, and the optimization-model method [35]. In the zonal-based method, a pair of the selected risk criteria is mapped into the horizontal and vertical axes, respectively, with the specific risk criteria varying across different studies [36–38]. However, this method is constrained by its limitation of considering only two criteria simultaneously. Conversely, the trade-off method involves assessing the trade-offs between objective project requirements and the subjective preferences of managers [22,39]. Notably, it considers only two factors and does not apply to select strategies from the alternatives. The WBS-based approach is recognized for its foundation in both risk management and the project management process [21,40]. However, it is unknown whether the strategies obtained are the optimal solutions to the strategy selection problem. While these methods have substantially contributed to the selection of risk response strategies from various viewpoints, their limitations concerning the criteria for response strategy selection and quantitative resolution render them inadequate for addressing multi-objective requirements.

The optimization approach is suitable for multi-objective requirements by constructing a mathematical model for risk response strategy selection [12,17,21,41]. Existing research on RRSS based on optimization models has been conducted mainly at the single-project and PP levels. Regarding the single-project level, in order to select the optimal project risk response strategies, Zhang and Fan [40] presented an integer programming model, where the total risk response effects, considering the project budget, schedule and quality, were treated as the objective. However, risk interaction, which is widely recognized as having a significant impact on risk response, was overlooked in their study. To incorporate the effect of the risk interaction, Chu and Wang [12] thereupon proposed an RRSS optimization model, in which the impact of the risk to influence other risk factors and the degree affected by other risks were considered. The results demonstrated that the selected response strategies considering risk interaction were more effective than not. Noting that the implementation of risk response strategies may lead to secondary risks that could interfere with the achievement of project objectives. Zuo and Zio [42] further designed a mixed-integer optimization mode with the objective of minimizing project cost and duration for determining optimal primary and secondary risk response strategies. The outcomes of this study provide valuable insights for managers to better manage primary and secondary risks simultaneously. The above analysis revealed that RRSS at the single-project level has been extensively studied. However, PP-level risk response has received limited research attention. For selecting an appropriate PP risk response strategy combination, Ahmadi-Javid, Fateminia et al. [21] presented an optimization model based on the project WBS, and the model incorporates two types of dependencies among risks and interdependencies among work packages.

Table 1
Summary of methods for risk response.

Approaches	No. Ref	Features
The zonal-based method	[36–38]	Two criteria can be considered.(horizontal axis and vertical axis)
The trade-off method	[22]qualitative analysis.	Either consider two factors or make trade-offs based on qualitative analysis.
The WBS-based method	[21,40]	Focus on problem-solving rather than seeking optimal solutions.
The optimization-model method	[12,15,21,46]	Multiple objectives can be considered, and optimal solutions can be found quantitatively.

However, project dependency of great attention in research on PP risk management has not been discussed in their study. These dependencies could lead to delays or changes in other related projects [43] and unpredictable reactions in PP [44]. Considering the impact of project dependency on RRSS in PP [45], advanced an interval optimization model under the uncertain response budget to yield the risk response decisions outcome, where project dependency was measured by the additional returns from the PP. Despite these inspiring results of the above studies, the interactions between response strategies, which show positive or negative synergies, have not been emphasized in existing research. Table 1 provides a brief description and commentary of the methods for risk response mentioned above.

To remedy the above issue, this study proposes a method combining the BID and the optimization model to select risk response strategies in PP. A BID, characterized as a decision model, encompasses a probabilistic graphical structure composed of graphical and conditional probability distributions [47]. Constructing a BID involves adding decision nodes and value nodes onto a BN [48], which supports RRSS by computing the expected value of each response strategy combination. By leveraging BNs, interactions among risks, projects, and response strategies can be quantified, enabling the assessment of their impact [49]. Building upon this, the BID model captures a decision maker's options and preferences to determine the optimal decision policy. Thus, a BID - optimization model is suitable for modeling decision problems' interactive and probability dependencies, which takes into account the risk interactions, response interactions, and dependencies among the projects in PP wide, and helps to satisfy the multi-objective demand. For clarity, objectives for the selection of risk response strategies based on the optimization approach are provided in Table 2. Furthermore, Table 2 compares and summarizes the traditional optimization-model method and the BID-optimization method.

2.3. Findings of literature review

Drawing upon insights gleaned from the literature review, the following conclusions emerge.

(1) A critical imperative exists to analyze the impact of ESRs on PP risk management;
(2) The integration of BID with optimization methods constitutes a crucial prerequisite for the selection of risk response strategies.

Based on the literature review and research findings, it is evident that conducting risk management from the perspective of external stakeholders is feasible. Furthermore, to effectively fulfill the multi-objective requirements for RRSS, the integration of BID with optimization methods is deemed necessary.

3. Model construction

This section describes the framework of the ESR response strategies selection model. Firstly, a Probability-Sensitivity Matrix is formulated to identify the key ESRs, followed by the acquirement of response strategies aligned with these key ESRs. Subsequently, leveraging the key risk response strategies and their associated impact values, a BID model is developed to amalgamate the aforementioned interactions, thereby computing the anticipated values for various response strategy combinations. Finally, by factoring in stakeholder contentment and strategy costs, an optimization model for the selection of risk response strategies is devised to derive potential combinations that adhere to specified constraints. By combining expected values and candidate combinations, the optimal strategy combination could be selected based on organizational requirements. The availability of the optimal strategy combination is judged by the residual risk impact value. The detailed process is shown in Fig. 1.

3.1. Construction of key risk assessment matrix

In a PP, many ESRs exist and focusing on all of them poses a huge cost and time challenge to the organization. In order to achieve optimal efficiency in the use of limited organizational resources, it is essential to prioritize them and focus most time and effort on key risks. This will ensure the efficient use of effort to manage the risk deemed. The Probability-Sensitivity Matrix is a common tool to provide a focus for risk analysis, which assesses the level of probability of occurrence (probability) and how degree the risks have an influence on other risks (sensitivity) [51]. Based on the results of the probability and sensitivity assessments, risks could be prioritized and key risks would be identified. Therefore, in this study, the Probability-Sensitivity matrix is introduced to prioritize risks, and risk response strategies were formulated and selected according to the priorities. The probability of occurrence and sensitivity of risks could

Table 2
A Comparison of studies using optimization for risk response selection.

Approaches	No. Reference	Project-wide	Portfolio-wide	Risk interaction	Response interaction	Project dependency	single-objective	multi-objective
Optimization-model method	[50]	✓		✓			✓	
	[15]	✓		✓	✓			✓
	[41]	✓		✓	✓		✓	
	[21]		✓	✓				✓
	[45]		✓	✓		✓	✓	
BID-optimization method	This study		✓	✓	✓	✓		✓

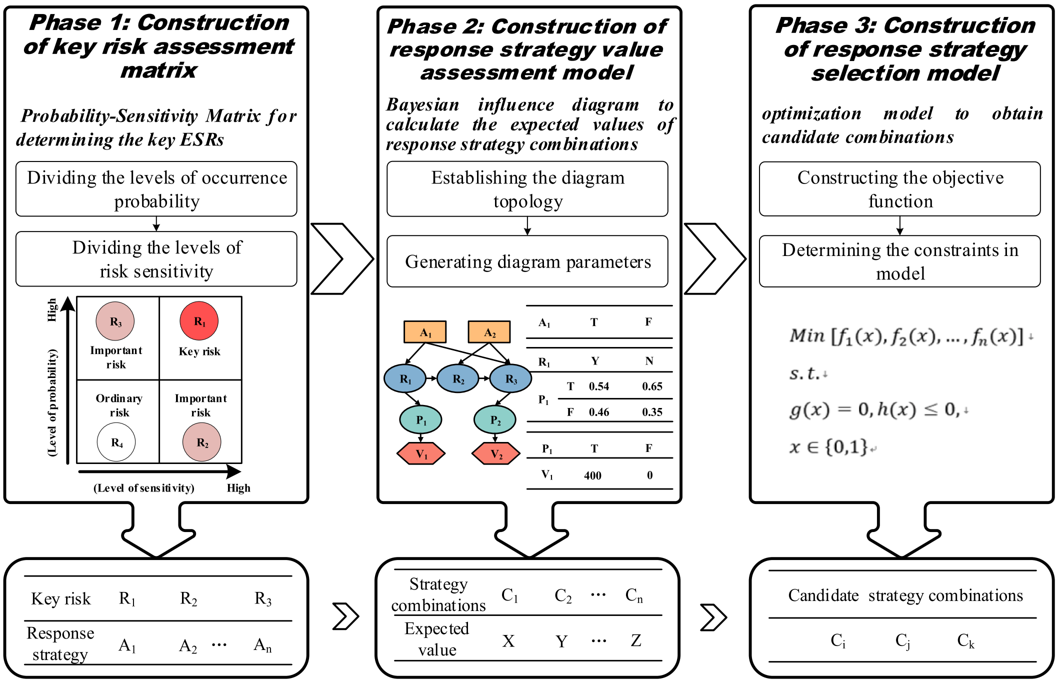


Fig. 1. Proposed framework for selection of risk response strategies.

be classified into several levels using the Probability-Sensitivity Matrix for risk assessment. The ESRs-PP BN model proposed by Bai, Kang et al. [27] for ESRs assessment is suitable for estimating the probability and sensitivity level of ESRs, given the alignment of their research focus with the current study. Based on this, risks with higher probability and sensitivity are selected as key risks. Therefore, a two-dimensional coordinate system of probability and sensitivity levels would be established to determine the risk levels (see Fig. 2). According to the identified key ESRs, risk response strategies could ultimately be formulated drawing upon historical precedents and expert insights.

In the example shown in Fig. 2. The horizontal coordinate indicates the sensitivity level of the risk and the vertical coordinate represents the magnitude of the probability of the risk. The significance of the ESRs is categorized into three levels. Key risk (R_1) has the highest salience, owing to its high probability of occurrence and sensitivity level. Therefore, emphasis will be directed towards this aspect. Significant risks (R_3 and R_2) will receive relatively less time and resources, given their lower probabilities and sensitivities

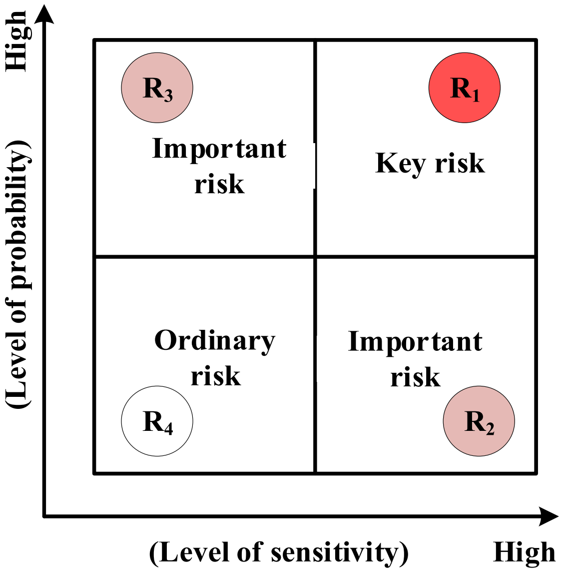


Fig. 2. Probability-sensitivity matrix.

compared to R_1. As for moderate risk (R_4), a strategy of maintaining awareness is deemed suitable, provided that their sensitivities and probabilities remain at lower levels.

3.2. Construction of response strategy value assessment model

PP occurs in a nonlinear, complex and interactive environment [52], in which the various elements of the PP, such as projects, stakeholders, and risks, interact with each other. In present study, the BID model is deemed appropriate for capturing the causal relationships among ESRs and the dependencies among projects within the PP, owing to its capacity to represent variable interactions and probabilistic interconnections. In addition, risk responses are not considered separately but are interrelated. The selection of related responses can affect their influence on the PP, which appears as a positive or negative synergism [15]. The relationship between risks, projects and responses and their effects on the PP are shown in Fig. 3.

To acquire the expected value of the strategy combination and support the selection of the optimal response strategies, a BID model is developed in this section. According to Shan and Liu [49], it is known that establishing a BID model contains three aspects of work: (1) Establishment of diagram topology involves two main components. The first component comprises nodes representing variables, and the second component consists of arcs delineating interactions and probabilistic dependencies among the nodes. The topology of chance nodes should be determined, and then decision nodes and value nodes are added according to the needs of management; (2) Determination of diagram parameters. These parameters indicate the probability dependency relationship between chance nodes and prior values (functions) of decision nodes; (3) Implementation of probability propagation. Given the evidence, the probability of the chance node and the expected value of the value node are calculated. In current study, the specific meaning of nodes is introduced in Step1.

Step1. Determination of diagram topology

The BID is the expansion of BN by adding decision nodes and value nodes. It is a directed acyclic graphical representation of a decision scenario originally proposed by Howard and Matheson [53], which consists of three types of nodes (shown in Fig. 4): (1) **decision nodes** (rectangular) representing decisions to be made; (2) **chance nodes** (ellipse) representing uncertainties modeled by probability distributions; and (3) **value nodes** (diamond-shaped) without children nodes, representing the (expected) value that reflect the preferences of decision-maker [54]. The interpretation of arcs varies based on the target node. Solid arcs to chance nodes or the value nodes indicate probabilistic dependence and functional dependence, respectively, while the dashed arcs pointing at a decision node indicate the information known at the time of making that decision. The specific definitions and meanings of the nodes in this study are described below.

(1) **Chance nodes.** Chance nodes are uncertain events or variables, as shown in node R_i and P_i in Fig. 4. In this study, Chance nodes are the projects and risks confronted with the PP. The arc between risks indicates the interactions between them, and Interpretive Structural Modeling is used to determine the interactions between risks based on literature review and expert knowledge. As shown in Fig. 4, the arc pointing from R_1 to R_2 indicates that the occurrence of R_1 may trigger the occurrence of R_2. The technology, resource, and benefit dependency proposed by Schmidt [55] are depicted as directed arcs of project nodes according to the dependencies between projects. The arc directing from P_1 to P_2 shows that P_2 depends on P_1. The procedure for modeling different types of project dependencies could be referred to Bai et al. [27]. A directed arc from the risk node to the project node signifies that the occurrence of the ESR will impact the project. The PP managers are invited to determine all correspondences between ESRs and projects according to the risk situation of PP at a particular stage.

(2) **Decision nodes.** Decision nodes represent a set of optional actions as nodes A_i, shown in Fig. 4. In this study, decision nodes are proposed response strategies for key risks. The arc pointing from response strategy to risk implies that the strategy is used to respond to the risk. Additionally, the selection of decision nodes necessitates a specific criterion: a directed path encompassing all decision nodes must exist. This criterion ensures the establishment of a temporal sequence (total order) of decisions, known

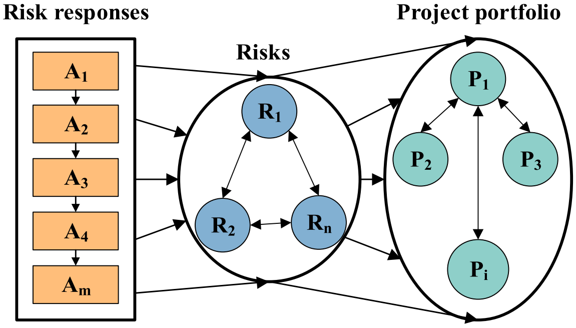


Fig. 3. Relationship between risks, projects and responses.

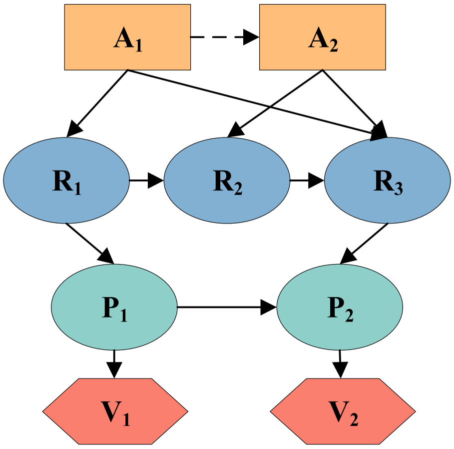


Fig. 4. An example of the Bayesian influence diagram.

as the sequencing constraint, which upholds the “no-forgetting” property of the Bayesian Influence Diagram (BID): the decision maker retains recollection of past observations and decisions [56]. Following the above interpretation, the directed dashed arc of A_1 pointing to A_2 indicates that the choice of A_1 precedes that of A_2.

(3) **Value nodes.** Value nodes express the cost and benefit derived from the decision, as node V_i shown in Fig. 4. In this study, the value node V_i is the impact value on the project P_i (i.e., reduced impact value of risk) after the execution of the risk response strategies, which could cover the impact of the risk on the project [57].

Step2. Determination of diagram parameters

In the BID model, different nodes of the diagram topology correspond to different types of parameters. After identifying all the nodes, (1) For chance nodes, the conditional probability tables (CPTs) are the parameter tables of conditional probability distributions corresponding to chance nodes. Chance nodes without parents are called root nodes expressed by a prior probability, which represents the probability of their occurrence in a given state. Other chance nodes use prior conditional probability, which quantifies the strength of the dependency between two nodes, to indicate the probability dependence relationship. To obtain the diagram parameters, it is imperative to define the states of the chance nodes. The risk node has two states, Yes (*Y*) and No (*N*), indicating whether a risk occurs. The project node has two states, success (*T*) and failure (*F*), indicating whether a project succeeds. A project is considered a failure if it cannot deliver the desired output in scope, quality, or schedule. Theoretically, CPTs may be formulated using statistical data, expert judgment, or a combination of the two (Weber et al., 2012). However, due to the uniqueness of a PP, historical data is generally insufficient or unavailable. Therefore, this study makes full use of the rich experience and knowledge of experts to obtain CPTs for chance nodes. Table 3 shows a CPT of chance node R_2. As an example, conditional on strategy A_2 being taken and risk R_1 occurring, the probability of risk R_2 occurring is 0.55, and the probability of R_2 not occurring is 0.45. (2) Decision nodes do not possess any parameters, and their states are denoted as *Y* and *N*, representing the implementation or absence of a response strategy; (3) For value nodes, each value node has an expected value (function) and gathers information about the impact value of the decision from the perspective of managers. The calculation of the impact value of decisions on each project in the value node is determined through the computational framework introduced by Ref. [27], which is equal to the impact value for each project. Table 4 shows the expected value of the value node V_1. As seen from Table 4, when the project P_1 is successfully implemented, it could produce a value of 400.

Step3. Implementation of probability propagation

Once the diagram topology is constructed, the CPTs and expected values are determined. Based on the available evidence, the probabilities can be propagated using the BID model developed in **GeNIe2.3**. This enables us to obtain the expected values of different response strategies. Taking Fig. 4 as an example, the expected value of response strategy combinations (A_1A_2, A_1, and A_2) could be obtained through the probability propagation of the BID model. Note that the sum of the expected values of A_1 and A_2 may not equal the expected value of A_1A_2. The effect arises from the positive or negative synergism of response strategies, which is described in

Table 3
Conditional probability table of the chance node $\boldsymbol{R_2}$.

A_2		Y		N	
R_1		Y	N	Y	N
R_2	Y	0.55	0.40	0.65	0.50
	N	0.45	0.60	0.35	0.50

Table 4

The expected value of node $\boldsymbol{V}_1$.

P_1	T	F
V_1	400	0

Section 1. Based on the results of the probability propagation, the decision with the highest expected value will be selected by the manager.

3.3. Construction of response strategy selection model

Due to the constraints of PP implementation and the requirements of the objectives to be achieved by taking strategy combination, not all of the above combinations of response strategies can meet the requirements of the organization. Therefore, after obtaining the expected values of each response strategy combination, the mathematical approach developed in this section aims to select the candidate combination of response strategies for ESRs. This approach involves multi-objective optimization through binary integer programming. In the first step, two objectives (cost minimization and stakeholder satisfaction maximization) are modeled, considering different assessment criteria for response strategies. In the second step, constraints are proposed to create a balance among the selected strategies. Eventually, an appropriate method is chosen to solve the Pareto optimal solution (Candidate response strategies combination).

The question addressed in this study is selecting the most desirable risk response strategy combinations for ESRs. To solve the problem, zero–one decision variables are utilized to signify the implementation of specific response strategies for risk mitigation. A value of one is assigned to the decision variable if the response strategy is chosen, while a value of zero indicates non-implementation. Therefore, it is appropriate to apply zero-one integer programming to solving the discrete optimization problem. In the following, the notations and their meanings are firstly given in Table 5.

To optimize the selection of risk response strategies, a multi-objective model is constructed based on cost minimization and stakeholder satisfaction maximization. In general, the cost and expected value of strategies are regarded as two fundamental dimensions of response strategy selection [58]. The majority of managers aspire to manage risks efficiently by minimizing costs while maximizing expected value, a key consideration within the BID model. The primary objective of risk response selection in the optimization model is to minimize costs. Currently, the focus of stakeholder theory in risk management is on considering the views and perceptions of stakeholders with high salience [59]. Stakeholders are the beneficiaries of PPs and their satisfaction has a significant impact on the implementation and outputs of PPs [1]. The stakeholder satisfaction with the response strategies is determined based on their performance and efficiency [18]. If the satisfaction with different response strategies of stakeholders is not properly met, the satisfaction of the whole PP will be seriously affected. Therefore, it becomes imperative to integrate stakeholder satisfaction considerations into the selection of strategies, with the secondary objective being the maximization of stakeholder satisfaction through risk response initiatives. Specifically, the two objective functions of minimizing costs and maximizing stakeholder satisfaction can be obtained, as shown in Eqs. (1) and (2):

$$Min\ C = \sum_{i=1}^{n} (c_i x_i) \tag{1}$$

$$Max\ Q = \sum_{i=1}^{n} (q_i x_i) \tag{2}$$

During the selection of response strategies, managers prioritize elements such as time and cost implications associated with these strategies. If the chosen combination of risk response strategies instead negatively affects PP in terms of cost and time, it could cause serious problems that outweigh the impact of the risk itself. Therefore, cost and schedules are used as constraints. Constraints also

Table 5

The related notations along with their definitions.

Notation	Definition
Q	The whole stakeholder satisfaction with implementing selected response strategies
C	The total cost for implementing selected response strategies
B	The budget for implementing risk response strategies
T	The schedule for implementing risk response strategies
A_i	The set of risk response strategies, $A = \{A_1, \ldots, A_m\}$
c_i	The cost of implementing a risk response strategy A_i
t_i	The time-consume of implementing risk response strategies A_i
q_i	The stakeholder satisfaction with implementing risk response strategies A_i
$\overset{\text{�}}{M}$	The set of all pairs of strategies that exclude each other
$\overline{M}$	The set of all pairs of strategies that cooperate with each other
X_i	The binary integer decision variable. X_i is equal to 1 if risk response strategy A_i is implemented and otherwise X_i is equal to 0

include other constraints related to risk priorities and response strategies themselves.

The constraints within the model can be categorized into two distinct types. The first type pertains to financial and temporal considerations, encompassing the budgetary limits for enacting risk response strategies and the requirement to contain each risk within a predefined timeframe. The second type of constraint is associated with the response strategies themselves. Generally, actual requirements limit the combinations of strategies that can be selected. The model allows two kinds of pairwise constraints: exclusion and cooperation. Exclusion dictates that only one strategy can be chosen within a pair, while cooperation mandates that selecting a specific strategy necessitates the concurrent selection of another designated strategy. Thus, the constraints can be determined, as shown in Eqs. (3)–(7).

$$S.T.\ \sum_{i=1}^{n}(c_i x_i) \leq B, \tag{3}$$

$$\sum_{i=1}^{n}(t_i x_i) \leq T, \tag{4}$$

$$x_i + x_{\acute{i}} \leq 1, (A_i, A_{\acute{i}}) \in \overset{�}{M}, \tag{5}$$

$$x_j + x_{\acute{j}} = 1, \left(A_j, A_{\acute{j}}\right) \in \overline{M}, \tag{6}$$

$$\begin{gathered} x_i, x_j \in \{0,1\}, \\ i, \acute{i}, j, \acute{j} = 1, 2, \ldots, n \end{gathered} \tag{7}$$

In this model, the objective function (1) maximizes all the stakeholder satisfaction with risk response strategies. The objective function (2) minimizes cost budgets of risk response strategies. For constraints, Eq. (3) ensures that the cost of implementing risk response strategies meets the budget requirements. Eq. (4) ensures that response strategy combinations are finished in a stipulated time. In the constraint, the value of parameters B and T can be obtained from the schedule and budget. Eq. (5) states that strategies A_i and $A_{\acute{i}}$ exclude each other. Eq. (6) states that selecting one strategy requires another specific strategy to be also selected. Eq. (7) is a binary mode indicator.

The multi-objective optimization model is used to obtain Pareto optimal solutions, i.e., candidate combinations of ESR response strategies. Managers can select the schemes according to the specific circumstances of the PP.

3.4. *Selection of optimal response strategies*

The above process details the establishment process of the two models in Section 3.2 and 3.3, and the selection process of a risk response strategy is described in this section.

The selection of response strategies is a systematic work that requires the joint efforts of the BID and optimization models. The solutions derived from the optimization model consist of multiple candidate response combinations, which represent the amalgamation of risk responses aimed at maximizing stakeholder satisfaction and minimizing costs. These solutions are commonly referred to as candidate response combinations. After applying the BID model, the execution of n response strategies can yield n^2 sets of combinations and their expected value, the permutations of all strategies in the state of execution or not. The expected values of the candidate response combinations can be evaluated, which is the basis for selecting the optimal response combination. Then the availability of the candidate strategy combinations is judged by the residual risk impact values in PP, which could be obtained via the probability propagation of the BID model. Upon selecting the candidate strategy combination, the residual risk response value becomes ascertainable. Should this value fall below the risk tolerance threshold, the combination is deemed feasible. Conversely, if the residual value exceeds the risk tolerance threshold, the solution is considered infeasible and subsequently eliminated. Organizational managers will choose among the feasible combinations based on preferences of the organization for cost, risk impact value, and stakeholder satisfaction.

Conversely, if the anticipated value of all candidate strategy combinations does not sufficiently mitigate risks to the utmost risk tolerance level, or if the solution does not meet managerial expectations, an iterative process will ensue. This iterative process will facilitate trade-offs among the pivotal elements until a conclusive decision criterion is established. Based on the acceptable trade-offs, the iterative process involves readjusting the plan concerning budget (*B*) and time (*T*) of the project according to objective requirements and the project stakeholders' experience.

4. Illustrative example

This section demonstrates an illustrative example that validates the availability and applicability of the proposed model. Its main objective is to elucidate the successful implementation of this model within practical PP and its effectiveness in solving ESRs problems. Specifically, the model is demonstrated using a construction project portfolio (CPP) as detailed by Bai, Kang et al. [27], comprising five projects characterized by diverse attributes. The project descriptions and the cost of failure (*CF*) of P_i are shown in Table 6.

4.1. Model application

4.1.1. Acquisition of key external stakeholder risks

As described in Section 3.1, the key risks of the CPP are assessed by the Probability-Sensitivity-Matrix combined with the results of the ESRs assessment model proposed by Bai, Kang et al. [27]. Their model effectively integrates the interaction between risks, dependency between projects, and correspondence between risks and projects, which is consistent with the considerations of the present study. Consequently, this model is deemed applicable to our research for assessing ESRs. Through the ESR assessment model, the probability of occurrence and sensitivity level of each ESR could be obtained. The subsequent steps for identifying key ESRs are outlined as follows. Firstly, the risk is divided into four levels according to the probability of occurrence, and the range is below 30 %, 30%–40 %, 40%–50 %, and above 50 %; Secondly, the sensitivity of risk is also divided into four levels, the range is non-hypersensitive, insensitive, sensitive, and hypersensitive. On this basis, the Probability-Sensitivity Matrix is established.

As shown in Fig. 5, the risk levels are clarified, serving as a foundation for subsequent actions. According to the management requirements and risk tolerance thresholds specific to the CPP, the identification of ESRs warranting responsive strategies is facilitated. Notably, response strategies are devised for risks exhibiting a probability or sensitivity level of at least the third level (risks with a sensitivity level of sensitivity and above or a probability of 40 % or higher). Fig. 5 illustrates these identified ESRs, with detailed explanations provided in the work by Bai, Kang et al. [27]. Managers and their teams discuss and propose nine response strategies according to their experiences in similar projects or risk events, as shown in Table 7. This study aims to select response strategies for these key risks that satisfy the constraints to reduce the impact value of risks on PP and thus satisfy the highest risk tolerance of CPP.

4.1.2. Assessment of response strategy value

To respond to ESRs by considering the interactions in CPP, a BID that visualizes variable relationships is established to assess the expected values of response strategies. The BID represents an extension of a BN incorporating decision and value nodes. The BN model, as described in Bai, Kang et al. [27], comprises a two-layer structure, encompassing the ESR subnetwork and the CPP subnetwork. By synthesizing historical experience and judgments of experts and managers, the CPP subnetwork is built based on different dependencies among projects. The complete ESR subnetwork is constructed using an interpretation structure matrix to prevent the loss of risk interaction information. According to the correspondence between ESRs and construction projects, the two subnetworks are integrated into a two-layer (ESR-CPP) BN structure. Based on this two-layer BN structure, the diagram topology of the BID model can be constructed. Initially, the linkage of decision nodes is achieved by identifying the ESRs targeted for specific risk response strategies. Following this, each project node is associated with a value node representing the impact value on the project. These two sequential steps culminate in the attainment of the comprehensive diagram topology of the BID model, as depicted in Fig. 6.

By combining the empirical data of experts and referring to the similarity aggregation method given by Sakar, Koseoglu et al. [60], the various states and corresponding probabilities of different nodes could be obtained. Adhering to the principles of expert selection and the method of calculating expert weights proposed by Qiao, Liu et al. [61], a group of experts was chosen to elicit parameters for this study. A comprehensive depiction of their backgrounds and the corresponding weights assigned to them is provided in Appendix A. For demonstration, $S5R1$ is chosen as an example and the conditional probabilities of $S5R1$ are shown in Table 8. For instance, When A_1 is taken, and $S1R2$ and $S4R1$ occur, the expert evaluates the likelihood of $S5R1$ by using linguistic variables such as “medium” and “high”. Then, based on the similarity aggregation method, the fuzzy language is transformed into a crisp value which is treated as the probability of $S5R1$. A complete process to calculate the parameters is available in Bai, Kang et al. [27].

As stated above, decision nodes represent the array of response strategies delineated for critical risks, as outlined in Table 7. The input for the value nodes corresponds to the impact value (i.e., the cost of failure, as detailed in Table 6) for the project under the scenario where all ESRs occur, as its maximum can cover the impact of the risk on the project, shown in Table 9.

Once parameters for all nodes are elicited, the comprehensive BID model is constructed using ***GeNIe2.3*** software, visually illustrating the relationships among projects, risks, and response strategies, as depicted in Fig. 6. The BID framework facilitates the propagation of probabilities to derive expected values for various combinations of risk responses, exemplified by the value assignment within node A_8 as shown in Fig. 7.

4.1.3. Selection of risk response strategies

Given the constrained resources of the organization, achieving the most cost-effective risk response decisions necessitates accounting for resource constraints. Consequently, it becomes imperative to select the optimal combination of response strategies for mitigating risks.

Within the CPP, nine response strategies are identified for addressing key risks. Project managers have established two primary

Table 6
The project description of CPP.

No. Project	Description	Cost of failure ($)
P_1	Welfare institute construction project	4,100,000
P_2	Shantytown reconstruction project	3,400,000
P_3	Residential green project	4,300,000
P_4	Public green belt project	6,700,000
P_5	Talent apartment green project	5,600,000

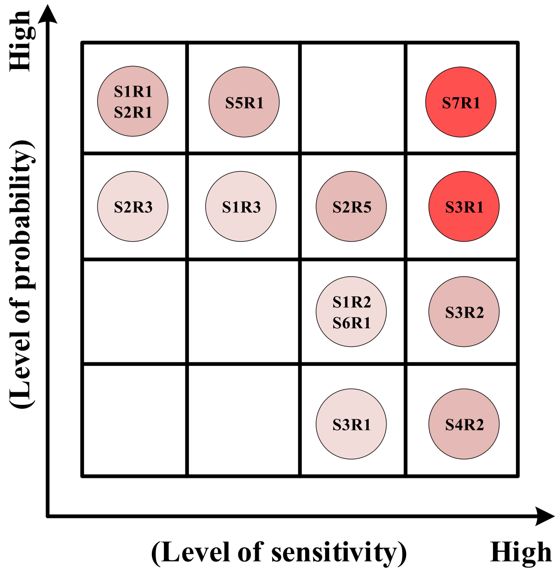


Fig. 5. The probability-sensitivity matrix of CPP.

Table 7
The risk responses for CPP.

No.	Risk response strategies
A_1	Conducting further market surveys and communicating with users
A_2	Formulating and implementing candidate emergency alternatives
A_3	Improving the communication channels and strengthening communication abilities
A_4	Training employees
A_5	Utilizing decentralized management and improving the decision-making process
A_6	Developing financing channels
A_7	Reserving safety stock
A_8	Establishing safety incident emergency handling procedures
A_9	Strengthening supervision and inspection

criteria: stakeholder satisfaction and cost, alongside constraints related to both cost and time. PMI [1] suggests that stakeholder satisfaction levels are frequently discerned through direct stakeholder engagement. Consequently, in this study, stakeholder satisfaction regarding each response strategy is assessed based on feedback from relevant stakeholders involved in the CPP. Satisfaction levels are categorized into five scales, ranging from 1 to 5, indicating: very dissatisfied, dissatisfied, basically satisfied, satisfied, and very satisfied. Table 10 shows the satisfaction of each stakeholder with different strategies. According to project documentation, the total available budget for implementing response strategies is $ 964,000 (*B*). Besides, PP delays due to response strategies are limited to a maximum of 90 days (*T*). The costs and the time required for each risk response are shown in Table 11.

Taking into account these parameters and variables, the optimization model for risk response strategies in this study can be formulated as follows:

$$Min\ C = \sum_{i=1}^{n} (c_i x_i) \tag{8}$$

$$Max\ Q = \sum_{i=1}^{n} (q_i x_i) \tag{9}$$

$$S.T.\ \sum_{i=1}^{n} (c_i x_i) \leq 964,000, \tag{10}$$

$$\sum_{i=1}^{n} (t_i x_i) \leq 90, \tag{11}$$

$$x_1 + x_7 \leq 1, (A_i, A_{i'}) \in \hat{M}, \tag{12}$$

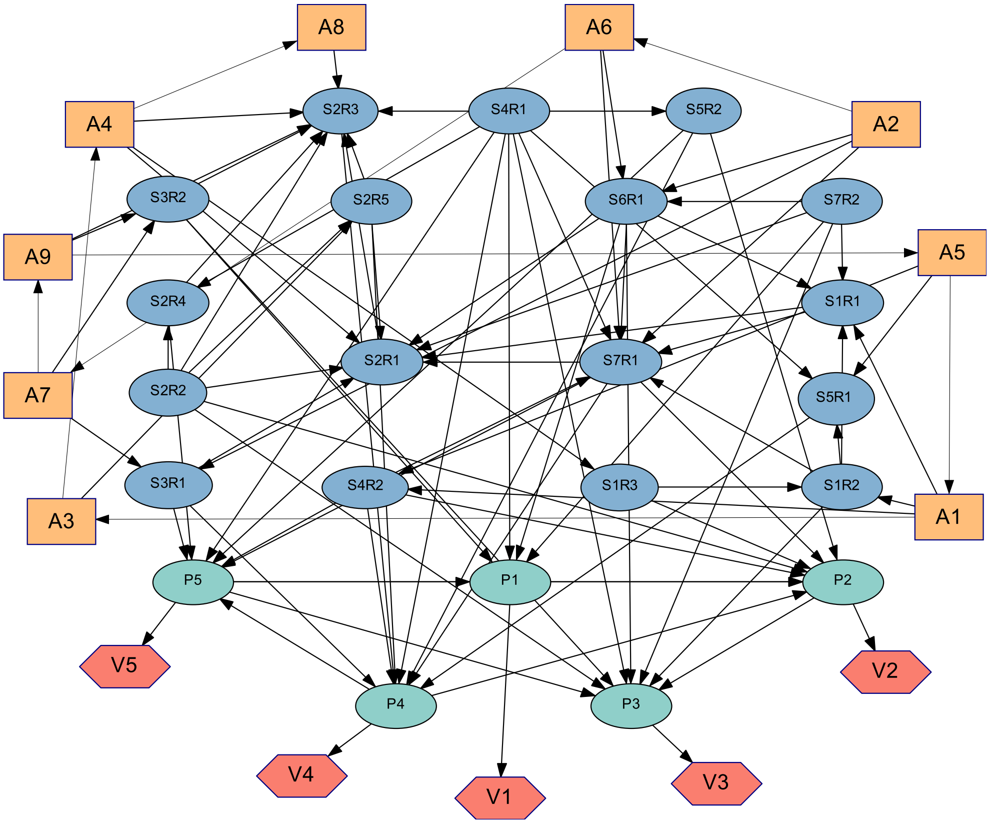


Fig. 6. The BID of CPP.

Table 8
The conditional probability table of $S5R1$.

S1R2	Y				N			
S4R1	Y		N		Y		N	
A_5	Y	N	Y	N	Y	N	Y	N
Y	0.9276	0.9482	0.6602	0.7352	0.75933	0.8185	0.3237	0.4062
N	0.0724	0.0518	0.3398	0.2648	0.2407	0.1815	0.6763	0.5938

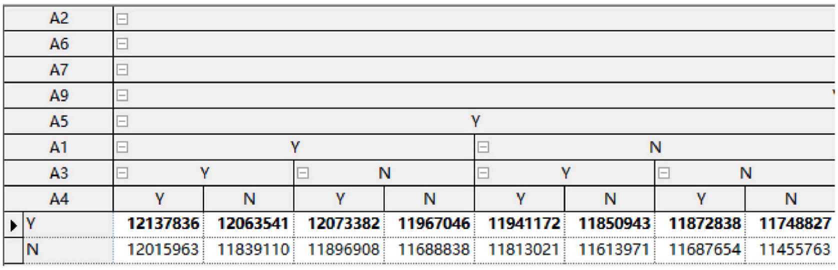
Table 9
The values of value nodes.

No. Value nodes	Impact value ($)
V_1	4,100,000
V_2	3,400,000
V_3	4,300,000
V_4	6,700,000
V_5	5,600,000

$$x_9 + x_{13} = 1, \left(A_j, A_{j'}\right) \in \overline{M}, \tag{13}$$

$$\begin{gathered} x_i \in \{0,1\}, \\ i, i', j, j' = 1, 2, \ldots, 9 \end{gathered} \tag{14}$$

Constraints (12) and (13) are related to the requisite and prerequisite constraints for implementing risk responses for each risk. The constraint (12) indicates that at most one can be selected between response A_1 and A_7 of $S1R2$. According to constraint (13), risk $S2R5$ must choose a response strategy in either A_9 or A_3. After substituting all the data, the Pareto optimal solution (candidate response strategy combination) could be obtained by ***Python.3.10.5***, i.e., several candidate response strategy combinations that satisfy the



A2	⊟							
A6	⊟							
A7	⊟							
A9	⊟							
A5	⊟ Y							
A1	⊟ Y				⊟ N			
A3	⊟ Y		⊟ N		⊟ Y		⊟ N	
A4	Y	N	Y	N	Y	N	Y	N
▸ Y	**12137836**	**12063541**	**12073382**	**11967046**	**11941172**	**11850943**	**11872838**	**11748827**
N	12015963	11839110	11896908	11688838	11813021	11613971	11687654	11455763

Fig. 7. The part of expected values of different combinations of response strategies.

Table 10
The satisfaction of each stakeholder for different strategies.

Responses	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Average (q_i)	3	4	4	3	3	4	5	3	4

Table 11
The requirements of risk response strategies.

Responses	Cost (c_i)($)	Time (t_i)(Days)
A_1	90,000	30
A_2	140,000	12
A_3	160,000	10
A_4	120,000	28
A_5	160,000	14
A_6	200,000	15
A_7	300,000	10
A_8	100,000	28
A_9	65,000	36

constraints, as shown in Table 12.

4.2. *Results and analysis*

(1) Selection of optimal response strategy combination

To ascertain the optimal combination of response strategies for PP ESRs, the candidate strategy combinations in Table 12 should be consulted with the expected values in Fig. 7. It is imperative to validate the viability of these candidate combinations by assessing whether their expected values can mitigate the impact of risk on PP to meet the critical threshold. Concerning the actual situation of the CPP, the critical threshold is determined as 3,000,000 based on their budget by the CPP manager in this example. According to Bai, Kang et al. [27], if the risk impact value of the CPP amounts to $14,273,000, the expected value of the optimal response strategy combination should be at least $11,273,000, calculated as the difference between the CPP's risk impact value and $3,000,000. In other words, the reduced impact value of the risk should be greater than or equal to 11273000. According to the comparison, the expected values of C_3 and C_6 are lower than $11,273,000, which does not satisfy the expected value requirements for cost minimization and stakeholder satisfaction maximization. C_1, C_2, C_4, and C_5 are feasible options.

Given the unique context of each PP, coupled with the relationship among projects, risks, and response strategies, the PP manager possesses the flexibility to opt for varying strategy combinations tailored to specific demands regarding cost, satisfaction, and anticipated strategy values. For example, Suppose the primary goal of the organization is to achieve the highest benefits. In that case,

Table 12
The candidate strategy combinations of the optimization model.

No.	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	C	Q	expected value
C_1	0	1	1	0	0	1	1	0	1	865,000	21	11,507,412
C_2	0	1	1	0	1	0	1	0	1	820,000	20	11,460,687
C_3	1	1	1	0	1	1	0	0	0	752,000	18	11,14,4126
C_4	0	1	1	0	0	0	1	0	1	665,000	17	11,606,767
C_5	0	1	0	0	0	0	1	1	1	605,000	16	11,495,002
C_6	1	1	1	0	0	0	0	0	1	455,000	15	11,229,545

C_4, the combination with the highest expected value, is the best combination of strategies, as the budget allows. At this point, the manager should adopt the strategy combination of C_4. C_4 is the combination of strategies consisting of Risk Response Strategies 2, 3, 7, and 9. These strategies involve implementing candidate contingency alternatives (A_2), Improving the communication channels and strengthening communication abilities (A_3), Reserving safety stock (A_7), Strengthening supervision and inspection (A_9) by managers. These actions can effectively reduce ESRs due to a lack of collaboration among contractors and unqualified quality inspection. By implementing these strategies, the project can be completed, and the highest expected utility value can be achieved. If an organization wants to meet basic risk response requirements at minimal cost, then C_5 will be the first choice for managers to reduce costs. Conversely, if the organization places a higher emphasis on stakeholder value and aims to maintain a high level of satisfaction in its risk response, C_1 can effectively assist in achieving these objectives.

In the eventuality of a worst-case scenario, where none of the candidate strategy combinations yield an expected value surpassing $11,273,000, the manager sought resolution by convening discussions with both the team and domain experts. Subsequently, the manager opted to alleviate constraints related to costs and time. Specifically, adjustments were made to the total costs and days delayed within the multi-objective function, while maintaining the integrity of the other constraints intact. Then, the multi-objective optimization model was solved by ***Python***. Constraints are iteratively relaxed until the termination criterion is met.

(2) Comparison of model performance

To comprehensively evaluate the model's efficacy, this study conducts a comparative analysis between the proposed model and the optimization model, which currently holds prominence in research concerning risk response strategy selection.

Based on the results (Table 12) obtained from the model proposed in this study and the results (the first 12 columns of Table 12) output from the optimization model, this study compares the results of the choices under different scenarios. When cost is the main objective of the organization, the model proposed in this study will output C_5, while the optimization model will output C_6. Note that the reduced impact value of risk after the adoption of C_6 does not meet the requirements of the organization as the residual impact value of risk is greater than the risk tolerance threshold of the organization. If the organization considers stakeholder satisfaction as the most important objective, according to the model proposed in this study, C_1 would be chosen and the optimization model selects the same combination. The choice is in line with the requirements of the organization. When the main objective of the organization is to reduce the impact of risk, C_4 would be the strategy combination chosen for the organization. If solely relying on the optimization model, additional objectives and constraints must be incorporated, there is an inevitable increase in the level of complexity associated with solving the model to a certain extent. Conversely, the integration of the BID model with the optimization model not only mitigates the complexity of model resolution but also facilitates a comprehensive consideration of the interrelationships among risks, projects, and response strategies. From the foregoing analysis, it becomes evident that under specific organizational objectives, the optimization model can yield comparable results to those generated by the model proposed in this study. Nonetheless, when confronted with diverse management requisites within the organization, the options provided by the optimization model may not be applicable.

In summary, the analysis presented above underscores the efficacy of the proposed RRSS decision model for ESRs in adeptly determining the optimal strategy combination through the integration of expected values and candidate combinations. This model not only furnishes a theoretical framework for stakeholder management aimed at mitigating incurred losses but also serves as a versatile instrument for the selection of risk response strategies.

5. Discussion

5.1. Theoretical implications

The theoretical implications are discussed from two aspects. First, this study extends prior research on PP risk response in terms of external stakeholders. For one thing, conflicts and risks arise due to the different interests of different external stakeholders, which greatly impact the implementation of PP. The proposed model of RRSS in this study could select the most appropriate combination of ESR response strategies with limited resources. A theoretical basis is provided to manage ESRs in PP. For another, since different stakeholders may view the same risk situation and response strategy in quite different ways, the attitude of stakeholders towards risk management needs to be considered. In this study, human elements, such as attitudes and feelings, are considered in the response strategy selection. That is, integrating stakeholder satisfaction into risk response strategy selection offers a valuable foundation for developing future research pertaining to stakeholder risk response.

Second, to overcome the problem of selecting ESR response strategy for PP, a new selection method of risk response strategy is proposed through combining BID and the optimization model. Notably, the selection of response strategy should be based not only on the risk itself but also on the impact of these interactions. If the specified number of related response combinations are selected or the influence of project dependency is considered, synergism results will enhance the individual effect of each response. In our proposed method, interactions among ESRs, projects, and response strategies are considered, while most previous studies for RRSS failed to consider these interactions simultaneously. This practice contributes to increasing the expected benefit and lower execution costs, thus improving the efficiency of ESR management. Overall, this study considers interactions among risks, projects, and risk responses to facilitate the rationality of research on risk response.

5.2. *Managerial implications*

The managerial implication of this study is twofold. First, the present study provides a quantitative multi-objective RRSS method to generate an optimal risk response strategy combination to handle ESRs, contributing to the shift of managers to a new risk management tool. This method allows managers to select an optimal strategy combination based on their experience and the management requirements of PP. In this proposed method, the construction and resolution process of the RRSS model is given. Unlike previous study, the proposed framework can help decision makers satisfy multiple goals for RRSS. Specifically, the objectives of the framework include response cost minimization, stakeholder satisfaction maximization, and response expected value maximization. The first two objectives are satisfied through the Pareto solution obtained from the optimization model, and the last objective is satisfied by the solution of the BID model. Based on cost minimization and satisfaction maximization, candidate response combinations with satisfying value is selected based on organizational requirements. The constraints of the framework are related to the cost, time spent by the response, and the associated nature of the response.

Second, the Pareto optimal risk response strategy combinations can be obtained by solving the model. In practice, there are a variety of organizations with different requirements for cost, expected value, and stakeholder satisfaction of strategy combinations. Through our proposed model, the appropriate response strategy combinations for different organizations could be selected according to the different expectations of the organization while satisfying the three objectives. Moreover, the organization can assign weights to the three objectives and select the appropriate strategy combination from the candidate combinations. If no feasible combination of strategies is found in the initial phase, a trade-off between the project budget and time can be provided until the stopping rule is met. Of these, only the optimization model needs to be solved cyclically. Notably, the Pareto solutions of the optimization model require reference to the results of the BID model and a judgment as to whether the threshold for risk effects is keeping with the ranges. In general, the findings are instructive for practitioners in the field of PPM.

5.3. *Limitations and future research*

Despite these valuable findings of this study, limitations remain. In reality, the expected value of risk responses does not necessarily cover the impact value of risk since there are always uncertainties or errors in a risk management process, alleviating the risk instead of fully controlling it. In the future, the project manager's expected value of the risk response effects could represent the degree of risk control. Furthermore, although this study considered stakeholder satisfaction in the construction of the optimization model, the satisfaction of different stakeholders is represented by dimensionless processing, ignoring the inconsistent importance of different stakeholders. Therefore, selecting risk responses based on the preferences of different stakeholders is a prospective direction.

6. Conclusion

Risk response strategy selection is an essential process of risk management. In the ESR management of PP, risk response is influenced by the interactions among its variables. Therefore, selecting response strategies based on the consideration of interactions is necessary. In this study, the research question of "***How can an optimal combination of ESR response strategies be selected considering PP interaction?***" is proposed. The response is as follows.

Considering the interactions between ESRs, projects and response strategies, an approach combining BID and optimization models is proposed to select combination of ESR response strategies. First, the key ESRs are identified through a Probability-Sensitivity Matrix, followed by relevant risk response strategies presented for subsequent selection. Second, to provide references for selecting response strategies, the expected values of different strategy combinations are calculated based on the BID model. Thirdly, considering cost and stakeholder satisfaction, the candidate strategy combinations are obtained via a multi-objective optimization model. Based on the output of the above two models, the candidate response strategy combinations that satisfy the three objectives, i.e., expected value, cost, and stakeholder satisfaction, are obtained. Organizational managers could select the appropriate solution that meets their different requirements for expected value, cost, and stakeholder satisfaction. Finally, a numerical example is adopted to validate the applicability and effectiveness of the model. Additionally, the superiority of our proposed model under different scenarios is verified via performance comparison. Based on the results, managers can choose the optimal strategy combination that aligns with the different risk response needs of the organization. For instance, if the primary goal of the organization is to achieve the highest benefits, they can choose the strategy combination with the highest expected value. In our analysis, we found that the optimal strategy combination is C_4 with an expected value of 11,606,767. The proposed model comprehensively considers the interactions between risks, projects, and risk responses, enhancing the desirability of expected outcomes and reducing the execution costs of PP.

Ethical statement

This manuscript does not involve any ethical issues.

Data availability statement

The authors are unable or have chosen not to specify which data has been used.

CRediT authorship contribution statement

Libiao Bai: Writing – review & editing, Funding acquisition, Conceptualization. **Shuyun Kang:** Writing – original draft, Methodology, Data curation. **Fang Li:** Writing – review & editing, Visualization, Software. **Ziwen Zhang:** Writing – review & editing, Supervision, Software. **Jiayu Li:** Validation, Software, Formal analysis. **Xixi Luo:** Writing – review & editing.

Declaration of competing interest

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Appendix A. Information on experts

Experts	Professional position	Years of experience	Education level	Age	Score	Weight
Expert 1	Senior	20–29	PhD	30–39	$5 + 4+5 + 2 = 16$	0.213
Expert 2	Senior	10–19	PhD	30–39	$5 + 3+5 + 2 = 15$	0.200
Expert 3	Junior	6–9	Master	<30	$4 + 2+4 + 1 = 11$	0.147
Expert 4	Senior	10–19	PhD	30–39	$5 + 3+5 + 2 = 15$	0.200
Expert 5	Junior	≤5	Bachelor	<30	$4 + 1+3 + 1 = 9$	0.120
Expert 6	Junior	≤5	Bachelor	<30	$4 + 1+3 + 1 = 9$	1.120

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