ISSN Online: 2821-1936

Transactions on Data Analysis in Social Science

Journal Homepage: https://transoscience.ir

Optimization Approaches in Selecting Project Risk Response Strategies

M. Torkaman[1], R. Ansari[2,*]

[1] M.Sc. student in Construction Engineering and Management, Department of Civil Engineering, Faculty of Civil Engineering and Surveying, Qazvin Branch, Islamic Azad University, Qazvin, Iran.
[2] Assistant Professor in Civil Engineering, Faculty of Engineering and Technology, Imam Khomeini International University (IKIU), Qazvin, Iran.

ARTICLE INFO

Article History:
Received 3 March 2021
Received in revised form 11 April 2021
Accepted 13 May 2021
Available online 1 June 2021

Keywords:
Risk Response, Optimization Model, Risk Response Strategy, Risk Response Management, Risk Dependencies

ABSTRACT

Project risk management is a fundamental component of the project management process that provides the foundation for enhancing reliability indices, improving safety assessment criteria, and increasing the overall probability of project success. Among its various dimensions, risk response management plays a crucial role, as it directly addresses the measures required to mitigate, transfer, accept, or avoid risks after they have been identified and assessed. While a significant body of research has focused on risk identification, classification, and evaluation, fewer studies have systematically investigated practical tools and methodologies related to risk response strategies. Existing evidence suggests that merely identifying and assessing risks, without designing and implementing appropriate response strategies, fails to ensure project resilience and may even exacerbate vulnerabilities in critical phases of project execution. Therefore, a structured and comprehensive review of previous studies on project risk response strategies is essential to consolidate current knowledge, identify methodological gaps, and provide guidance for practitioners and researchers. The present review seeks to analyze the state of the art in risk response management, highlight the progress achieved in selecting optimal strategies, and explore their implications for enhancing efficiency, cost control, and sustainability in diverse project environments. By mapping the existing literature, this study aims to advance theoretical understanding and contribute practical insights for strengthening project risk management systems.

1. INTRODUCTION

Project risk management is one of the most critical topics discussed in the theory and implementation of various industries [1]. According to the Project Management Guide, risk is defined as an uncertain event that, if it occurs, impacts at least one project objective [1]. The project environment and its characteristics shape the relevant risk management [2]. The goal of risk management is to increase the likelihood of project success. This is achieved

* Corresponding Author: raminansari@ENG.ikiu.ac.ir
Assistant Professor in Civil Engineering, Faculty of Engineering and Technology, Imam Khomeini International University (IKIU), Qazvin, Iran.

http://dx.doi.org/10.47176/TDASS.2021.53

through the systematic identification and evaluation of risks, providing methods to respond to risks, and maximizing opportunities [3].

A systematic approach to risk has led to the emergence of the risk management process, gradually developing from the 1990s in relevant sciences. The initial point is that risk management is recognized as a process in various references, such as Chapman and Ward (2003) and Pipatanavong (2001) [3][4]. Various processes for risk management have been proposed in different domains, but they share a similar structure. Generally, as shown in Figure 1, a conventional risk management process consists of five stages: risk management planning, risk identification, risk analysis, risk response, and risk monitoring and control. According to Kano (2003), all stages of the risk management process are equally important, and incomplete execution of any of them leads to ineffective risk management [5].

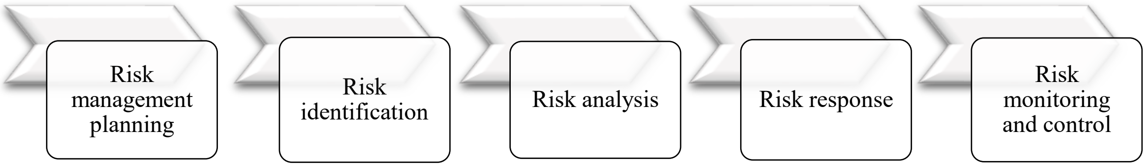

Fig. 1. Steps in the risk management process

The examination of the literature on the subject indicates significant deficiencies in the area of selecting risk response strategies for projects. Relevant studies are predominantly conceptual models that provide a general overview of the impact of risks on projects and strategies for responding to them. Research in project risk management has shown considerable growth in the construction industry over the past four decades [6].
It is observed that risks exist due to the involvement of various contract parties, such as employers, contractors, and consultants, each having a different perspective on project risks [7]. Employers, being stakeholders and decision-makers in construction projects, exhibit different behavior towards project risks compared to contractors [8]. The systems used for project risk management predominantly focus on quantitative risk analysis, limiting the reuse of risks, issues, response strategies, and experiences from previous projects for the development of new projects [6][10].

Research indicates that the construction industry tends to use a limited number of risk management techniques. Real project risk assessment requires an effective mechanism for gathering individual assessments. This review delves into studies and researchers' efforts in this field, examining the methods for selecting the best risk response strategies to address the risks in construction projects. Restrictive assumptions used in past studies have led to non-realistic proposed solutions, reducing the efficiency of previous models and methods [11].
In conclusion, no comprehensive model exists for evaluating project risk reduction measures. The review draws on the topic's literature and relevant studies to identify gaps in research, emphasizing the need for a more systematic approach in addressing project risks. The article proceeds to investigate and optimize existing strategies for responding to project risks, considering both strengths and weaknesses. The various optimization models proposed for risk response strategies are thoroughly examined, followed by analysis, discussion, and suggestions for future research. The conclusion section highlights the key findings of the review.

2. REVIEW OF PROJECT RISK RESPONSE STRATEGIES

Hillson (1999) categorized risk response strategies into two levels. The first level involves general response strategies, while the second level comprises a list of specific actions under each strategy. Using a general classification perspective, response actions to threats are commonly categorized into four types: avoidance, reduction, transfer, and acceptance [12]. Similarly, corresponding strategies for opportunities can be defined. Corresponding to the strategies of avoidance, transfer, reduction, and acceptance for threats, strategies of exploitation, sharing, enhancement, and acceptance (exploit, share, enhance, accept) can be defined for opportunities [13].

Researchers have explored various perspectives on studies related to the selection of risk response strategies for projects. One of the most comprehensive classifications is by Zhang and Fan (2014), who essentially categorized existing approaches to project risk response strategies into four classifications: tool-based approach, negotiation-based approach, breakdown structure-based approach, and optimization model-based approach [14].

In this study, this classification has been refined and presented in Figure 2. The following provides a brief explanation of each approach.

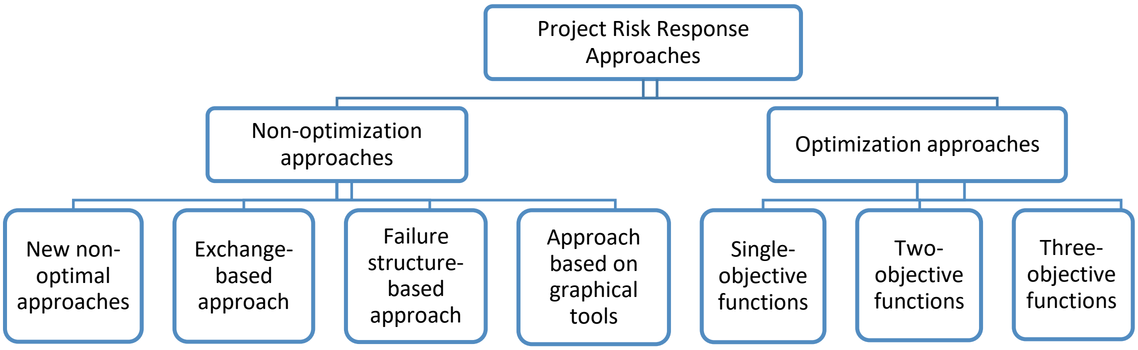

Fig. 2. Modified Classification of Project Risk Response Approaches

3. NON-OPTIMIZATION APPROACHES IN PROJECT RISK RESPONSE STRATEGIES

3.1. Graphical Tools-Based Approach:

Some researchers have proposed graphical tools for selecting risk response actions. In these tools, based on predefined criteria, an approximate region for identifying response actions is determined using a graph or a two-dimensional matrix. In most models presented for this approach, two criteria, such as probability and impact, are selected based on the characteristics of the risk and applied on two perpendicular and horizontal axes. As illustrated in Figure 3, various regions emerge from the intersection of the two axes, each indicating different response strategies. Therefore, the appropriate response strategy for each risk is identified based on the two relevant criteria and the corresponding region.

Fig. 3. Schematic of Graphical Approach

Flanagan and Norman (1993) proposed a framework based on the probability of occurrence and the impact of risk. They divided the area between the horizontal axis (risk impact) and the vertical axis (probability of occurrence) into different sections based on varying effects and probabilities. For risks located in each area, they introduced predetermined responses. Another study by Chart (1989) determined the risk-related strategy using two criteria: predictability and controllability. Elkezhaar and Fielding (1999) identified the risk strategy through the introduction of four strategies: presence, watching, contingency planning, and contingency plans. Other criteria that can be selected and applied on the graph axes include the weighted probabilities of internal and external project risks or the systemic nature and manageability of risks (risk scope and risk importance for the project).

In another study by Pinn (2003), a risk response planning chart was presented based on decision maker desirability extracted from the probability-impact risk matrix. In Pinn's method, each risk area is first defined based on two criteria: probability and impact. If a reduction action can change the risk area, that action is chosen, and the final risk area determines the response strategy. Lopez and Salmeron (2012) used a method similar to Pinn's to select the risk response strategy after identifying and evaluating the risks in an information technology project. They used two risk factors, probability and impact, in the chart, dividing it into four sections and four strategies: root cause elimination, avoidance, error stabilization, and reduction.

Reviewing existing research in this approach reveals the following results and points:

- Graphical tools approximately identify the response strategy, but they are not useful for selecting detailed responses.
- These methods generally determine one strategy for each area, while in the real world, different strategies should be considered for risks in each area.
- These tools only consider two criteria, but in practical issues, multiple criteria should often be examined.

3.2. Approach Based on Exchange Tools and Utilizing Pareto Boundary

The concept of Pareto boundary was introduced by Markowitz (1976) and has since become the basis for the formation of many decision-making techniques [24]. In solving a decision-making problem with a set of criteria, the effective boundary, curves of points in response space, is encountered. On one side of it, no other solution points exist, and on the other side, all solutions are non-efficient concerning points on the curve. Each point on this curve is better in some criteria and weaker in others compared to another. Therefore, choosing the final answer to the problem involves selecting from the points on the effective boundary, with the aid of lightening and weighting the options on this boundary. The exchange-based approach is also a two-dimensional approach and shares similar constraints with the approach based on graphical tools. To obtain candidate risk response strategies, exchange criteria are determined based on objective constraints and project goals, as well as the preferences of managers among criteria related to risk, such as profit, cost, success probability, work loss percentage, duration, quality, etc. Suitable strategies are then selected from among the available nominees based on the Pareto boundary rule, refining optimal responses, and refining sets of efficient responses based on decision-maker priorities [25].

Various studies have employed different criteria. For example, in the study by Pipatanapong and Watanabe (2001), they introduced a risk management system titled the multi-part risk management process, encompassing all stages of risk identification, assessment, and response. In the response stage, by considering two criteria, potential post-implementation costs of risk management strategies along with the risk level, and comparing the calculated values, the best responses are chosen. Subsequently, by determining the effective responses, a Pareto boundary is identified, as illustrated in Figure 4, for the responses.[4]

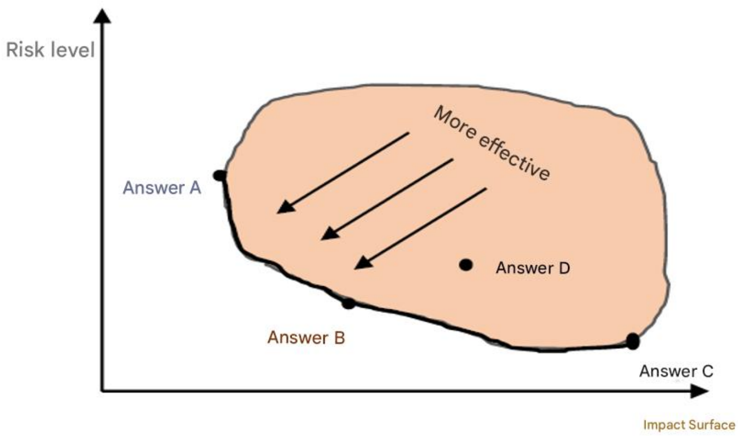

Fig. 4. Illustration of the Pareto Boundary by Pipatanapong and Watanabe

Kojawski (2002) in his study calculated the total costs of implementing a response and the risk costs after implementing the response for each option using a decision tree and simulated the cumulative probability distribution curve through Monte Carlo simulation. His two criteria were the probability of project completion within the budget and the predicted costs for project completion. The proposed approach in his research aimed to identify a set of risk response actions that either maximize the probability of success for a specified total cost or minimize the total project cost for a specified probability of success. The Pareto boundary in this study was determined by points corresponding to responses that have the least cost impact for a specific probability of success, marking them as efficient responses [26].

Chapman and Ward (2003) presented an approach based on risk efficiency, considering the balance between the cost of risk response and the level of risk these costs address. They introduced an environment diagram that illustrates both acceptable (efficient) and unacceptable regions, similar to Figure 4. Their chart, with the vertical axis representing the risk level and the horizontal axis depicting the cost of implementing the action, indicates that Response D is non-efficient due to being worse in both implementation cost and risk level compared to other actions. However, for Responses C, B, A, none of them has a complete superiority over the others, and a trade-off between criteria is needed to select the superior option [3]. Additionally, the cost of risk response and the percentage of work lost after implementing the response, along with the optimal Pareto solution, were mentioned in the research [27].
Another category of balancing models includes those based on multi-criteria decision-making methods. Mousavi et al. (2011) proposed a method for selecting risk response strategies using fuzzy decision-making in a fuzzy environment [28]. They used a fuzzy decision tree to calculate the importance of project risks based on several criteria and a graphic method. Then, they utilized TOPSIS technique to calculate, considering uncertainty conditions, the most suitable response program. This method used various criteria such as cost, time, project quality, and scope, taking into account secondary risks.

In another study, Nasirzadeh et al. (2013) evaluated risk responses by combining fuzzy sets [29]. In this approach, by considering factors such as cost, time, and project quality for each risk, one of the response methods is selected. The preferences of experts in group decision-making, using four prioritization methods, including desirability function, ordinal, priority matrix with numbers between 1 to 9, and fuzzy prioritization, were transformed into fuzzy prioritization using the method proposed in the study.
Furthermore, in the research by Binh and Hatao (2010), a risk response program for a mining project was presented based on group decision-making, using a fuzzy priority [30]. The quality of experts' information was assessed and weighted, and these weights were used to aggregate opinions and find the final priority. The best response strategy was chosen based on the performed ranking.

In discussing the methods and models presented in the comparative approach, several points can be highlighted: This approach considers only two factors and conducts analysis based on qualitative analysis.

Primarily, a specific performance threshold is defined, but there is no specific method for evaluating and selecting final responses based on this threshold.
Exchange criteria are determined based on the mental preferences of managers among risk-related criteria such as profit, cost, success probability, work loss percentage, duration, quality, etc.

3.3. Approach to Risk Response Based on Project Breakdown Structure

Another approach in the field of determining risk response is the project breakdown structure approach. In this approach, each activity in the project breakdown structure is considered, and appropriate responses are selected by comparing acceptable responses. The project breakdown structure is considered a significant tool in risk management and the project management process. Some researchers have utilized the project breakdown structure to establish a connection between the risk response strategy assessment model and other project management systems. The initial step in using the project breakdown structure as a method for selecting risk responses was taken by Chapman in 1979. The suitable response to risk is directly derived from the project breakdown structure and interacts with its associated activities in the project. This approach selects the risk response strategy for operational activities based on the analysis of the project's breakdown structure. In this study, a probabilistic enhancement methodology called "complementary probabilistic assessment and response techniques" is proposed, which identifies the elements of the project breakdown structure, examines related risks and responses. This method requires extensive studies in large projects to mitigate this issue. To reduce this problem, Cleland and his colleagues (1994) have presented a modified version of this model, where instead of examining the risks and responses of each activity in the set, pattern-checked activities are examined, and the results are generalized for all set activities. An initial sample set of rules can be developed to demonstrate how risk analysis for the sample activity is transformed

into a real activity, and then a set of strategies for all activities generated by the sample activity may be obtained. When the analyzed activity is real, identified risks and strategies can be directly formulated for that activity, or within the set, a set of strategies can be selected using an expected deviation index. When the analyzed activity is a sample, the set can be developed to show how risk analysis for this sample, which has become a real sample, is performed, and then a set of strategies may be obtained by the sample for all stated activities. Among the list of unintended changes in the project scope, candidate solutions for reducing these changes can be selected. However, it is not clear whether the obtained strategies for the problem are optimal solutions for selecting response strategies. The project breakdown structure approach as a tool for responding to risks has not been widely embraced by researchers. Perhaps the following reasons can be cited for this lack of reception:
The focus on cost elements and neglect of other project objectives is a drawback of the project breakdown structure-based method.
Lack of precise mathematical solutions is another disadvantage of this method.
It is unclear whether the obtained answers are optimal solutions for selecting response strategies.

3.4. Innovative Non-Optimization Approaches in Project Risk Response Strategies

In the study conducted by Fan et al. (2015), a systematic method for providing risk responses based on Case-Based Reasoning (CBR) has been proposed. The suggested approach utilizes a new decision-making paradigm to address project risk response challenges. This method differs from output-based approaches for generating risk response strategies (such as graph-based methods, comparative methods, structure-based activity breakdown, optimization methods).

By employing the proposed method, desirable risk response strategies can be obtained by retrieving and reusing information and knowledge from similar historical cases. The proposed method possesses clear logic and a straightforward computational approach. The steps involve: first, identifying the target case and historical cases; second, retrieving existing historical cases while judging whether the risks associated with each historical file are covered or similar to those of the target case; third, retrieving similar historical cases by measuring the similarity between each existing historical case and the target case; fourth, creating a solution for the target case based on similar historical cases.

This approach involves examining similar projects and reviewing project documents to find the best strategies for responding to potential project risks. This method is also employed for identifying risks based on a case-based causation approach in various studies aimed at preventing risk occurrences. [35-44].

As an example, in the research by Kumar and Viswanadam (2007), a causation-based case framework for a decision support system to support risk management in the project supply chain for construction projects has been established]41[.

Bajou and colleagues (2012) created a model based on case-based causation for a multi-agent system for risk management on the web platform for small and medium-sized businesses]37[. Dingwei and Jean Ping (2011) developed an auxiliary model for discrimination based on hierarchical analysis and case-based causation for risk management evaluation]38[. Li and colleagues (2013) also presented another model based on a case-based causation system with a detailed topic design and an automatic recursive mechanism for self-analyzing operational risks in metro exploitation]43[. The analysis and identification of risks in a ship repair project were also undertaken by Yu and colleagues (2014) based on the proposed approach]44[.

Banolz and colleagues (2017), in their research, utilized a combined product of Cross-Impact Analysis (CIA) and Interpretive Structural Modeling (ISM) to enhance predictive techniques for risk analysis. This study suggests a scenario-based method by combining interpretive structural foundations with the cross-impact analysis method. The combination of both methods allows the creation of a comprehensive risk network based on the cognitive assessment of managers and historical data. Consequently, it is anticipated that this model may encompass a large number of events and their interrelationships. Furthermore, CIA ISM enables the prediction of project results according to the likelihood of each event source (prior to project initiation), dynamic events (during project development), and result events at the end of project development. This increase in the predictive capacity of risk scenarios, without restricting the dissemination of the established model, enhances]45[.

As long as we discuss the topic of risk, we encounter uncertainty in the world of uncertainty. After implementing each of these approaches to select a response to mitigate potential risks, we are ultimately not certain about choosing the best and most optimal solution. Therefore, resorting to optimization methods to guide researchers towards more reliable responses is unavoidable. However, some limitations exist in the existing approaches. For example, only two criteria can be considered in the tool-based approach, and there is a lack of a more precise mathematical solution for the exchange-based approach and the structure-based approach. Additionally, all approaches, except for the structure-based failure approach, can only be applied to small projects where risk analysis is easily done directly without the need for discrete project activities. Therefore, there is a need for a new approach to selecting a project risk response strategy.

Table 1 presents the research conducted in the non-optimization approach along with a summary of the study's scope for each research to summarize the content of this section.

Table 1. Summary of Research Conducted in the Field of Non-Optimization Approaches

Author	Year	Field of investigation	Approach
Chart[16]	1989	Capability Forecast and Capability Management	**Approach based on graphical tools**
Flanagan and Norman [15]	1993	Probability Occurrence and Intensity Risk	
Algeria and Fielding[17]	1999	Degree Impact and Amount Capability Before Nose Risk	
Data and denominator [18]	2001	Probability Weight Risk Hi Domestic and Risk Hi Foreign Project	
Miller and Lazard[19]	2001	Capability Control Risk and Degree Importance Risk For Project	
Pini[20]	2003	Capability Admission Probability and Effect Risk	
Lopez and Salmeron[21]	2012	Ability to accept the probability and impact of risk	
Klein[25]	1993	Lack Certainty I see In Time , Cost and Quality Project	**- Exchange based approach**
Pipattanapyeong and Watanabe[4]	2001	Cost Case Waiting After Actions Strategy Answer To Risk and Amount Risk level Which strategy Answer Must To it arrive	
Kojawski[26]	2002	The probability of success for a given amount of total cost and the total project cost for a given amount of probability of .success	
Chapman and Ward[3]	2003	Balancing the cost of risk response and the level of risk	
Hamis[27]	2005	Cost Strategy Answer To Risk and Percentage From Work From Hand Gone Tidy With Strategy Reply to Risk	
Bing and Haitu[30]	2010	Priority Bandi Answer I see With Use From group decision-making and integration with logic Fuzzy	
Mousavi et al[28]	2011	Choice Risk Hey Important With Tree Decision and Choice Answer Suitable With Topsis and Numbers Fuzzy	
Nasirzadeh et al[29]	2013	Solution Problem Choice Answer With In Opinion Catch ,Cost Time and Quality and use From Decision Catch Group With Logic Fuzzy	
Chapman[31]	1979	performance Hi ,work venture Ha and Answer Hi venture that to activities Allocation Data been and.	**He turned around Based on the project breakdown structure**
Clean and Colleagues [32]	1994	Change In Method Chapman With Use From Activity Hey Pattern	
Seyed Hosseini et al[33]	2009	Choice Collection From Strategies ,Answer For Reduction Deviation From achieving To Range Project With Interest Catch From Structure Failure Work, structure Failure Cost and Structure Shakt Quality	
Fan and colleagues[34]	2015	Planned method based on case-based reasoning(CBR) Presented	**New non-optimization approaches**
Banuelos et al. [45]	2017	A scenario-based approach combining interpretive structural foundations By the method of reciprocal analysis	

4. OPTIMIZATION APPROACH IN PROJECT RISK RESPONSE STRATEGIES

The use of mathematical models and optimization approaches can help project management teams make optimal choices for responding to risks. Figure 5 shows that researchers have developed more optimization approaches in recent years. The optimization of elementary elements involves defining objective functions and measurement criteria for mathematical models, as well as considering limitations on the models' variables. Additionally, methods for solving mathematical optimization models are developed. To validate the mathematical model and solution method, researchers utilized performance verification approaches. The following classification introduces optimization models: objective functions and problem limitations, proposed solution methods, and validation methods used to date.

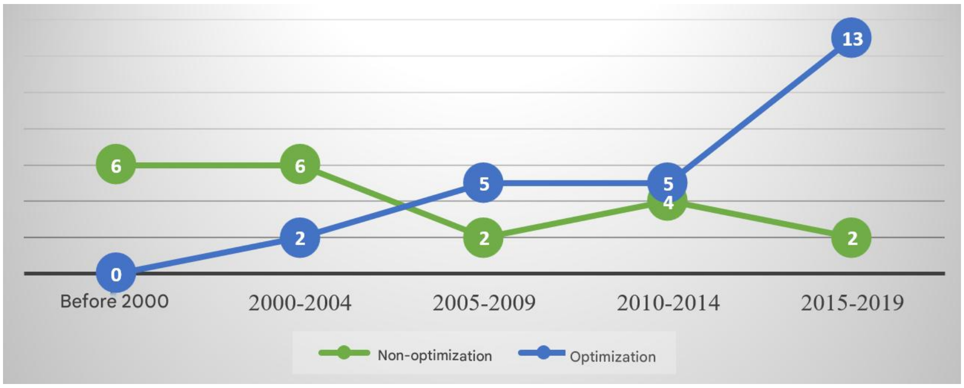

Fig. 5. Approaches Employed in Risk Response Strategies

4.1. Objective Functions and Constraints

After a comprehensive evaluation of the optimization model for project risk response strategies, it was concluded that the consequences of risks directly impact the time, cost, and approved quality of the project. Researchers have examined the effect of responding to risks on these project objectives. In exploring the objective functions in articles related to risk response strategies, all conducted research is summarized in Table 2.

Table 2. Overview of functions used in the optimization approach in selecting responses to risks

Research	Objective functions used		
	Cost	Time	Quality
Ben David and the Secret (2001)[11]	*	-	-
Ben David et al. (2002)[46]	*	-	-
Kayes et al. (2007)[47]	*	-	-
Kilik etal (2008) [48]	*	*	-
Fan et al. (2008)[49]	*	*	-
Popa and Marcotte (2008)[50]	*	*	*
Seyed Hosseini etal (2008) [33]	*	*	*
Gunen (2011) [51]	*	-	-
Fang et al. (2011)[52]	*	-	-
Rezaei Nik et al. (2011)[22]	*	*	*
Fang et al. (2013)[53]	*	-	-
Zhang and Fan (2014)[14]	*	*	*
Zhang (2016)[54]	*	-	-
Zhang and Zhou (2016)[55]	*	-	-
Sufi Fard and the Land of the Bafro (2016) [56]	*	*	*
Sufi Fard and Khakzarbafroyi (2017)[57]	*	*	*

Naji and Revava (2017) [58]	*	*	-
Marcho y Ka and Kochta (2017)[59]	*	*	*
Sufi Fard and Gharib (2017)[60]	*	*	*
Cheraghy et al. (2017)[66]	*	*	*
Ghasemi and Darvishpour (2018)[62]	*	-	-
Zhou and Zhang (2018)[63]	*	*	-
Wu et al. (2018) [64]	*	*	*
Rahimi et al. (2018) [65]	*	*	*
Slogan and Theory (2019) [66]	*	*	*

4.2. Classification of Optimization Approaches

As discussed in the second section of this research, the classification of approaches for selecting project risk response strategies was presented. The conducted research in the optimization approach can be categorized into three sections: single-objective functions (cost), multi-objective functions (cost-time), and three-objective functions (cost-time-quality). Figure 6 illustrates the extent of researchers' utilization of single or multi-objective functions in the optimization approach for project risk response.

Objective functions represent the articles that have introduced new optimization models to guide the directions of project risk response strategies. In one of the earliest studies on the optimization model for risk response, Ben-David and Raz (2001) proposed a general framework for decision support models to allocate risk reduction actions. In this research, they introduced probability matrices (P), impact matrices (I), and the expected value matrix (E), obtained by multiplying the transpose of the probability matrix by the impact matrix, for calculating the expected cost. The presented model aims to minimize the total cost, which is the sum of the cost of risk event occurrence and the cost of response actions.

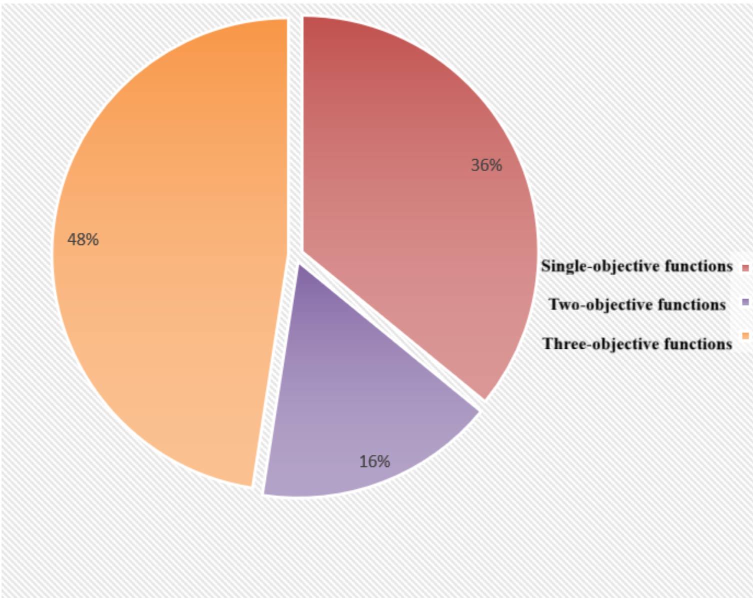

Fig. 6. Optimization Approach Objective Functions

The implementation of risk mitigation actions affects the probability and/or impact matrices, consequently influencing the expected value matrix and, in turn, the cost of risk occurrence. The execution of each response action also incurs costs. After implementing each action, the total cost is calculated, and the optimal responses are selected. This research primarily demonstrated that mathematical models can contribute to solving a practical and common problem. The model developed by Ben David et al. (2002) expanded by considering interactions between risk responses as constraints in the model [46].

$$AAC\ (X)^{\dagger} = \sum_{a=1}^{A} C_a X_{a\,.\,a} = cX_e \quad (1)$$

$$ERL^{\ddagger} = \sum_{r=1}^{R} (\sum_{s=1}^{S} p_{\,r\,.\,s})(\sum_{w=1}^{W} m_{\,r\,.\,w}) = (p_e)(m_e)' \quad (2)$$

$$ERL\ (X\,) = \sum_{r=1}^{R} (\sum_{s=1}^{W} f\ (p_{r.w}\,.Xv_{r.w}\,) + \sum_{s=W+1}^{S} P_{r.\,s}\,)\ (\sum_{w=1}^{W} h\ (m_{r.s}\,.Xu_{\,r\,.s}))$$

$$= (\,f\ (\,p\,.Xv\,)\ e\,)\ (h\ (\,M\,.X\,u\,)\ e)' \quad (3)$$

$$minimize\ TEC\quad (\,X\,)^{\S} = AAC\ (\,X\,) + ERL\ (X) \quad (4)$$

In this model, the set of activities is defined as W, the set of risks as R, the set of risk sources as S, and the set of risk mitigation actions as A. The first W resources are internal (work activities), and the next W-S resources are external.

The probability that source S causes risk event R is denoted as $P(r,\ s)$, and the financial loss to work activity W due to risk event R is denoted as $M(r,\ w)$. The variable for selecting a risk mitigation action is denoted as Xa, and the cost of the risk mitigation action is denoted as Ca.

The impact of action A on the probability of risk R occurring from source W is represented as $v(r,w,a)$, and the impact of action A on the effect of risk R caused by source S is represented as $u(r,s,a)$.

In the study by Fan et al. (2008), an approach to move from the current risk level to a desirable level is presented. This is achieved by implementing risk response actions, and three types of strategies are proposed, including prevention, post-event action, or a combination of both. While the prevention strategy only changes the probability of risk, the action strategy will change the risk effect.

The goal of the model is to achieve the minimum cost in reaching the desired risk level. The total cost is obtained from the sum of prevention cost Cp and action cost Cl. The calculation of action cost considers both financial loss and delay loss in planning. It is assumed that each risk has either a financial loss or a delay loss in planning.

In choosing a risk response strategy, three parameters are utilized: risk control capability, action cost, and project characteristics [49].

$$R_1 = P_1 *\ L_1 \quad (5)$$

$$R_2 = P_2 *\ L_2 \quad (6)$$

$$C_p = k\ \ ln\ (\frac{p_1 - \omega}{p_2 - \omega}) \quad (7)$$

$$C_{L\,.\,c} = r\ (L_1 - L_2) \quad (8)$$

$$C_{L\,.t} = \frac{s}{\beta}\ (e^{-\beta\,L_2} - e^{-\beta\,L_1}) \quad (9)$$

$$\mathrm{TC}_1 = \mathrm{C_p} + \mathrm{C_{L\,.c}} \quad (10)$$

$$\mathrm{TC}_2 = \mathrm{C_p} + \mathrm{C_{L\,.t}} \quad (11)$$

The current risk level (R1) is obtained by multiplying the existing probability (P1) by the existing impact level (L1), and the desirable risk level (R2) is calculated by multiplying the desired probability (P2) by the desired impact level (L2). The parameter "k" signifies the difficulty level of risk reduction, determined by past experiences and assessed by the manager. The ratio of uncertainties beyond control (ω) represents uncertainties that cannot be controlled by existing tools, with the control capability level denoted as ω-1.

The symbol "r" is used to indicate the cost of creating financial reserves for uncertainties, "S" represents the creation of time reserves, and "β" denotes the project float. The total cost for risks with financial impact is denoted as TC1, and the overall cost for risks without a time impact is TC2.

In the study by Seyyed Hosseini and colleagues (2009) [33], they proposed an integrated approach called Project Risk Response Planning, supporting the selection of response actions. This model introduces an Expected Deviation Index from the range, measuring the deviation from the specified project range while considering time, cost, and quality metrics. The aim is to minimize the project's deviation, considering the risk events and risk response actions as influential factors.

The presented index for measuring the project's deviation from the project range is defined as follows:

$$SED = 100 * \left(t * \left(\frac{T_0 - T'}{T_0} \right) + q * \left(\frac{Q_0 - Q'}{Q_0} \right) + c * \left(\frac{C_0 - C'}{C_0} \right) \right) \quad (12)$$

$$t + q + c = 1 \quad (13)$$

The proposed method is based on three main axes: project, risk, and response. Therefore, this method consists of three sections: project assessment, risk assessment, and response assessment, along with three rankings for project activities, risks, and responses. The overall framework of the method is structured as follows: initially, the project's time, cost, and quality values are measured. After identifying the risks and responses related to the project, it is assumed that all potential risks have been realized. By recalculating the time, cost, and quality values, the overall deviation is calculated. In the next step, by applying one of the candidate responses in each iteration, the deviation for each response is calculated. All responses are then ranked in descending order based on the highest reduction in deviation.

Fang et al. (2013) [53] presented an integrated approach in selecting risk response strategies. The proposed approach consists of five stages: constructing the project risk network, defining the performance function, determining the budget, identifying candidate responses, and optimizing the risk response plan. The introduced performance function (OF) represents the overall project risk level, derived from the sum of the expected losses of all risks, as expressed below:

$$OF = \sum_{i=1}^{N} P_i * G_i \quad (14)$$

where P represents probability and G denotes the risk effect.

In the study by Zhang and Fang (2014) [14], an optimization model was proposed for selecting risk response strategies. The model utilizes integer programming with the objective of maximizing the overall impact of risk responses. The objective function of the model for selecting a set of strategies that maximizes the estimated impact of risk response is as follows:

$$max\, Z = \sum_{i=1}^{m} \sum_{j=1}^{n} e_{ij} * x_{ij} \quad (15)$$

They formulated their model by considering a specific budget level for responding to project risks, a predefined time and quality for each project activity, and a set of constraints for prerequisites, interdependencies, and balance of selected risk responses.

The estimation of the impact of responding to risk after implementing strategy Ai on risk Rj is denoted as e_{ij}, *and the* variable indicating the choice of strategy j for risk i is represented by xij, taking values of zero or one.

In their study, Zhang and Zhuo (2016) [55] employed linguistic terms to assess the dependent relationship between each pair of risks. Initially, they proposed an attractiveness-based assessment method using the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) to measure the interdependency between risks. Subsequently, they introduced a preference coefficient indicating the relative importance of interdependency on the risk (the entropy approach). Finally, they presented a mathematical model that incorporates risk interdependency and risk impact for selecting project risk response strategies.

$$max\, Z = \sum_{i=1}^{m} \sum_{j=1}^{n} \lambda_j \, u\,(X_{ij}) \quad (16)$$

where λ_i represents the risk intensity, and $u(X_{ij})$ is the utility function. The available budget is defined as a constraint in the model. In comparison to the Analytic Hierarchy Process (AHP) method, the single-classification-based evaluation technique approach can significantly facilitate compatibility testing.
Sofifard and Gharib (2017) [60] present a mathematical model that examines the impact of risk reduction actions and their optimization based on various criteria related to the objective function, considering the type of project. For assessing the mutual effects of risks, they use the Risk Structure Matrix (RSM) method, composed of techniques such as Design Structure Matrix (DSM) and Analytic Hierarchy Process (AHP).

$$max\, Z = \sum_{k=1}^{K} \sum_{j \in St_j^k} Atr_{ij}^{lk} * X_{ij}^k + \sum_{f \in B^k} RNM_{fj} \sum_{o \in St_f^k} Atr_{of}^{lk} * X_{of}^k + \sum_{k=1}^{K} \sum_{j \in B^k} g_j^{lk} LM_j^k \quad (17)$$

$$l = 1\,.\,2\,.\,\ldots\,.\,L$$

The impact value resulting from the criterion l for response strategy i in risk j for activity k is defined as Atr_{ij}^{lk}. The synergistic effect generated for the assessment criterion l in risk j for activity k with g_j^{lk}, the level of risk influence f on risk j obtained from the Risk Design Matrix (RNM) with RNM_{fj}, if response strategy i for risk j activity k is chosen, 1; otherwise, 0: X_{ij}^k. If a synergistic effect is created for responses related to risk j for activity k, 1; otherwise, 0, with the variable LM_j^k.

Three criteria, cost, time, and quality, are considered in the objective function. The budget constraint dictates that the cost of selecting risk response strategies must be less than the budget at hand. Another constraint requires that response strategies be chosen in a way that the delay in executing each activity is less than the specified amount. Also, the response strategies should be selected in a way that the reduction in the quality of each project activity for all risks is less than a certain amount. Another constraint is applied so that if a certain number of response strategies for a set of specified risks are chosen, synergies are created for that risk, affecting its impact. Constraints related to prerequisites, co-dependencies, and balancing of selected risk responses are also considered.

Qasemi and Darvishpour (2017) [62] present a comprehensive three-stage framework. In the first stage, all risks, responses, and their relationships are identified. In the second stage, fuzzy theory, ant colony optimization, and DEMATEL play a crucial role in determining the importance and weight of risks. In the third phase, to achieve a realistic solution, a binary optimization model with budget constraints and other necessary constraints is utilized.

$$max\, f = \sum_{j \in J} v_j * x_j \quad (18)$$

X_j represents the decision variable, and the value of the risk response effect obtained by the matrix is denoted by v_j . Constraints are introduced to ensure that the risk cost, considering the cost of responding to the risk, the risk cost after responding to it, and the secondary risk cost, does not exceed the available budget in their research model.

4.3. Solution Methods for Mathematical Model

The solution methods can be categorized into single-objective and multi-objective functions. The outputs of these solution methods can also be divided into probable solutions and deterministic solutions. A wide spectrum of accurate methods, heuristic algorithms, and metaheuristic algorithms for solving single or multi-objective models addressing risk response strategies has been utilized by researchers.

The Branch and Bound algorithm has been used as a deterministic solution algorithm in the models of Zhang and Fan (2014), Rezaei Nik et al. (2011), Ben-David et al. (2002), Zhang and Zhu (2016) [14, 23, 46, 55].

Furthermore, heuristic methods like the Least Cost First algorithm, Most Risk Reduction First algorithm, Least Cost-to-Risk Ratio algorithm, and Probabilistic Search by Kayis et al. (2007) have been chosen for solving their model [47]. An heuristic model based on costs, compared to a time-based model and a genetic algorithm-based model, was employed by Kılıç et al. (2008) [48]. A simple heuristic algorithm was used by Ben-David et al. (2002) [46]. A Greedy Heuristic algorithm was employed by Ben-David and Raz (2001), Rezaei Nik et al. (2011), Ben-David et al. (2002), Fang et al. (2013) [11, 23, 46, 53].

The Genetic Algorithm was proposed as a metaheuristic method by Kayis et al. (2007), Kılıç et al. (2008), Fang et al. (2011), Fang et al. (2013) [47, 48, 52, 53]. Wu et al. (2018) used a dominant sorting process in the Genetic Algorithm in their model [64].

Naji and Ravanida (2017) presented the Gravitational Search Algorithm and Particle Swarm Optimization as solution methods for their mathematical model [58].

The Epsilon-Constrained Method is an exact solution method used in the articles of Sofifard and Khakzad Bafrooei (2016), Sofifard and Khakzad Bafrooei (2017), Sofifard and Gharib (2017) for solving the risk response strategy model [56, 57, 60]. The Evolutionary Algorithm was used in the model of Poppa and Marcut (2008) [50], and the Multi-objective Harmony Search Algorithm was mentioned as the second solution method in the article Sofifard and Gharib (2017) [60].

Marchewka and Kochta (2017) utilized the GUSEK software package [59], and Shahrooz and Nazari (2019) used the Ant Colony Algorithm [66].

Cheraghi et al. (2017) and Rahimi et al. (2018) also used the GAMS software [61, 65], and Guan (2011), Zhang (2016), and Zhu and Zhang (2018) used the Lingo software [51, 54, 63].

4.4. Validation Methods

After introducing the mathematical model and selecting the solution method, one of the most important stages is validating the model and the chosen solution method. In this stage, all proposed parts, including the model and the mechanism of the solution method, must undergo validation and proof. Ben-David and Raz (2001), Guan (2011), Sofifard and Gharib (2017), used sample problems to validate their models [11, 51, 60]. Ben-David et al. (2002) generated 11,520 random samples to test their model [46]. Models based on the design, testing, and construction of combinations of carbon fiber scenarios with low, normal, and high risk prevention costs were introduced by Kayis et al. (2007) [47]. Subsequently, random models with 15, 25, and 35 activities for evaluating a dual-objective model were produced by Kılıç et al. (2008) [48]. Poppa and Marcut (2008) utilized numerical experiments [50]. Seidhosseini et al. (2009) used an EPC project [33].

The selection of risk response in a power plant development project is a case study example used by Rezaei Nik et al. (2011) for their multi-objective model [23]. Fang et al. (2011), Fang et al. (2013), used the structure and systems related to a tram in a city as a case study for their model [52, 53]. Zhang and Fan (2014) verified their model by a project to build an air conditioning system [14]. Zhang (2016) studied a project of engineering renovation of a power substation [54]. Zhang and Zhu (2016) developed a software design for validating their model [55]. Sofifard and Khakzad Bafrooei (2016), Sofifard and Khakzad Bafrooei (2017) studied their model with the design, construction, and commissioning of a plant at the Research Institute of the Iranian Oil Industry [56, 57]. Cheraghi et al. (2017), Rahimi et al. (2018) used a 132-story tower named Saba Tower in District 22, Chitgar, Tehran, Iran, for validating their model [61, 65]. The case study of geothermal drilling in Iran was the case study of Qasemi and Darvishpour (2018) [62]. Zhu and Zhang (2018), Shahrooz and Nazari (2019) studied a construction project [63, 66]. Wu et al. (2018) investigated a real software development project [64], and Naji and Ravanida (2017) presented an example with 5 construction projects [58].

5. ANALYSIS, DISCUSSION, AND SUGGESTIONS FOR FUTURE RESEARCH

Previous research reviews indicate that risk management in construction projects is fraught with shortcomings that impact project performance. For many years, risk management in construction projects has had a reductionist approach, leading to poor results and low quality in project management. In most cases, risk management cannot provide a comprehensive analysis of the risks affecting a specific project to cover the consequences of risks that occur during project execution. To establish effective and efficient risk management, the use of an appropriate and systematic approach, and more importantly, knowledge and experience, is essential.

Researchers in their studies have mostly focused on three pillars: cost, time, and quality as objective functions. However, considering that inhibiting the occurrence of project risks is a complex and uncertain subject in project management, there is a need for more comprehensive and complex mathematical models. Additional risk features such as predictability [16], risk clarity [67], risk differentiation [68], manageability [69, 70], controllability [71], X-factor [72], project vulnerability [73], and the importance of risk [74], previously examined in risk assessment studies, should be incorporated into the strategic risk response model to contribute to a more comprehensive model.

Despite the merits of the conducted research, there are limitations. The main limitation is related to human elements. Human elements such as attitudes and emotions can be considered, as risk response strategies are formulated and executed by the project manager and his team, and different individuals may have different opinions on risk and risk response. For future research in this area, it is recommended that the construction of models for selecting risk response strategies should aim to overcome personality, emotions, motivation, background, and experience of individuals and consider quality constraints, work environment, environmental issues, stakeholder perspectives, and project cash injection flow as well. These study spaces can be used by researchers in this field.

6. CONCLUSION

The main goal of the risk response process is to create and develop various response options to risks to reduce negative consequences or increase positive consequences resulting from each risk. The researchers are seeking to reach an optimal model that simultaneously considers all the objectives of the risk management team. In this regard, an optimal solution is obtained so that the most desirable risk response strategies are provided to deal with the risk event for the use of all stakeholders in the project. By reviewing the conducted research and literature review, it became clear that no model has yet been presented that has fulfilled these objectives. Also, the existence of research gaps in the subject area is clearly seen. In this study, we focused on optimization and exact methods as the main axis of this discussion and examined all the presented optimization models by researchers. In addition, studies on non-optimization approaches have also been generally introduced. It can be stated that the examples used in previous studies are not mature enough to demonstrate the study space clearly. Given the stages of risk management in projects, especially the risk response process, there are ample opportunities for mathematical modeling and the use of optimization methods as clear deterministic solution methods.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

Acknowledgments

We would like to express our gratitude to all individuals who contributed to this project.

Declaration of Interest

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

REFRENCESS

[1] Rose, K. H. (2013). A guide to the project management body of knowledge (PMBOK® guide)–Fifth edition. Project Management Journal, 44(3). https://doi.org/10.1002/pmj.21345

[2] International Organization for Standardization. (2009). Risk management—Principles and guidelines. ISO.

[3] Ward, S. C., & Chapman, C. (2003). Project risk management: Processes, techniques and insights. Wiley.

[4] Pipattanapiwong, J., & Watanabe, T. (2000). Multi-party risk management process (MRMP) for a construction project financed by an international lender. In Proceedings of the Construction Engineering and Management Symposium (pp. 85–92).

[5] Conrow, E. H. (2003). Effective risk management: Some keys to success. AIAA. https://doi.org/10.2514/4.475818

[6] Forbes, D., Smith, S., & Horner, M. (2008). Tools for selecting appropriate risk management techniques in the built environment. Construction Management and Economics, 26(11), 1241–1250. https://doi.org/10.1080/01446190802468487

[7] El-Sayegh, S. (2008). Risk management and allocation in the UAE construction industry. International Journal of Project Management, 26(2), 271–278. https://doi.org/10.1016/j.ijproman.2007.07.004

[8] Bryde, D. J., & Volm, J. M. (2009). Perceptions of owners in German construction projects: Congruence with project risk theory. Construction Management and Economics, 27(11), 1059–1071. https://doi.org/10.1080/01446190903222403

[9] Kartam, N. A., & Kartam, S. A. (2001). Risk and its management in the Kuwaiti construction industry: A contractors' perspective. International Journal of Project Management, 19(6), 325–335. https://doi.org/10.1016/S0263-7863(00)00014-4

[10] Tah, J., & Carr, V. (2001). Knowledge-based approach to construction project risk management. Journal of Computing in Civil Engineering, 15(3), 170–177. https://doi.org/10.1061/(ASCE)0887-3801(2001)15:3(170)

[11] 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. https://doi.org/10.1057/palgrave.jors.2601029

[12] Hillson, D. (1999). Developing effective risk responses. In Proceedings of the 30th Annual Project Management Institute Seminars & Symposium (pp. 10–16).

[13] Hillson, D. (2001). Effective strategies for exploiting opportunities. In Proceedings of the Project Management Institute Annual Seminars & Symposium.

[14] Zhang, Y., & Fan, Z.-P. (2014). An optimization method for selecting project risk response strategies. International Journal of Project Management, 32(3), 412–422. https://doi.org/10.1016/j.ijproman.2013.06.006

[15] Flanagan, R., & Norman, G. (1993). Risk management and construction. Blackwell.

[16] Charette, R. N. (1989). Software engineering risk analysis and management. McGraw-Hill.

[17] Elkjaer, M., & Felding, F. (1999). Applied project risk management—Introducing the project risk management loop of control. Project Management, 5(1), 16–25. https://doi.org/10.1016/B978-0-7506-4503-4.50006-0

[18] Datta, S., & Mukherjee, S. (2001). Developing a risk management matrix for effective project planning—An empirical study. Project Management Journal, 32(2), 45–57. https://doi.org/10.1177/875697280103200206

[19] Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. International Journal of Project Management, 19(8), 437–443. https://doi.org/10.1016/S0263-7863(01)00045-X

[20] Piney, C. (2003). Applying utility theory to risk management. Project Management Journal, 34(3), 26–31. https://doi.org/10.1177/875697280303400304

[21] López, C., & Salmeron, J. L. (2012). Risks response strategies for supporting practitioners' decision-making in software projects. *Procedia Technology, 5,* 437–444. https://doi.org/10.1016/j.protcy.2012.09.048

[22] Hatefi, M. A., Seyedhoseini, S. M., & Noori, S. (2007). Risk response actions selection. *The International Journal of Applied Management and Technology, 5,* 385–408.

[23] Nik, E. R., Zegordi, S. H., & Nazari, A. (2011). A multi-objective optimization and fuzzy prioritization approach for project risk responses selection. In *2011 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 888–892). IEEE. https://doi.org/10.1109/IEEM.2011.6118044

[24] Markowitz, H. (1976). *Portfolio selection: Efficient diversification of investment.* Yale University Press.

[25] Klein, J. H. (1993). Modelling risk trade-off. *Journal of the Operational Research Society, 44*(5), 445–460. https://doi.org/10.1057/jors.1993.81

[26] Kujawski, E. (2002). Selection of technical risk responses for efficient contingencies. *Systems Engineering, 5*(3), 194–212. https://doi.org/10.1002/sys.10025

[27] Haimes, Y. (2005). A unified framework for risk assessment and management of sanitary and phytosanitary (SPS) situations. *Working Paper, Center for Risk Management of Engineering Systems, University of Virginia.*

[28] Mousavi, S. M., Raissi, S., Vahdani, B., & Hossein, S. M. (2011). A fuzzy decision-making methodology for risk response planning in large-scale projects. *Journal of Optimization in Industrial Engineering, 7,* 57–70.

[29] Nasirzadeh, F., Khanzadi, M., & Mianabadi, H. (2013). A fuzzy group decision-making approach to construction project risk management. *International Journal of Industrial Engineering & Production Research, 24,* 71–80.

[30] Sun, B., & Luo, H. T. (2010). Selection method of risk response schemes for mining project based on fuzzy preference relations. *Journal of Coal Science and Engineering (China), 16*(2), 221–224. https://doi.org/10.1007/s12404-010-0220-8

[31] Chapman, C. B. (1979). Large engineering project risk analysis. *IEEE Transactions on Engineering Management, 26*(3), 78–86. https://doi.org/10.1109/TEM.1979.6447349

[32] 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. https://doi.org/10.1057/jors.1994.119

[33] 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. https://doi.org/10.1111/j.1539-6924.2008.01187.x

[34] Fan, Z. P., Li, Y. H., & Zhang, Y. (2015). Generating project risk response strategies based on CBR: A case study. *Expert Systems with Applications, 42*(6), 2870–2883. https://doi.org/10.1016/j.eswa.2014.11.034

[35] Aarts, R. J. (1998). A CBR architecture for project knowledge management. In *European Workshop on Advances in Case-Based Reasoning* (pp. 414–424). Springer. https://doi.org/10.1007/BFb0056352

[36] 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. https://doi.org/10.1016/j.eswa.2012.01.001

[37] Chang, C., Ma, X., Song, X., & Gao, B. (2010). CBR-based emergency case generating system under engineering accidents. In *2010 IEEE International Conference on Progress in Informatics and Computing* (pp. 145–149). IEEE. https://doi.org/10.1109/PIC.2010.5687419

[38] Song, D., & Song, X. (2011). An audit decision aid system for management fraud risk assessment using AHP-CBR. In *2011 International Conference on Management and Service Science* (pp. 1–4). IEEE. https://doi.org/10.1109/ICMSS.2011.5998160

[39] Goh, Y. M., & Chua, D. (2009). Case-based reasoning for construction hazard identification: Case representation and retrieval. *Journal of Construction Engineering and Management, 135*(11), 1181–1189. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000093

[40] Jung, C., Han, I., & Suh, B. (1999). Risk analysis for electronic commerce using case-based reasoning. *Intelligent Systems in Accounting, Finance & Management, 8*(1), 61–73. https://doi.org/10.1002/(SICI)1099-1174(199903)8:1<61::AID-ISAF156>3.0.CO;2-6

[41] Kumar, V., & Viswanadham, N. (2007). A CBR-based decision support system framework for construction supply chain risk management. In *2007 IEEE International Conference on Automation Science and Engineering* (pp. 980–985). IEEE. https://doi.org/10.1109/COASE.2007.4341831

[42] 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. https://doi.org/10.1002/isaf.1342

[43] Lu, Y., Li, Q., & Xiao, W. (2013). Case-based reasoning for automated safety risk analysis on subway operation: Case representation and retrieval. *Safety Science, 57,* 75–81. https://doi.org/10.1016/j.ssci.2013.01.020

[44] 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). Springer. https://doi.org/10.1007/978-3-642-54930-4_6

[45] Bañuls, V. A., López, C., Turoff, M., & Tejedor, F. (2017). Predicting the impact of multiple risks on project performance: A scenario-based approach. *Project Management Journal, 48*(5), 95–114. https://doi.org/10.1177/875697281704800507

[46] Ben-David, I., Rabinowitz, G., & Raz, T. (2002). Economic optimization of project risk management efforts. *The Israel Institute of Business Research.*

[47] 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, 56*(1), 167–170. https://doi.org/10.1016/j.cirp.2007.05.040

[48] Kılıç, M., Ulusoy, G., & Şerifoğlu, F. S. (2008). A bi-objective genetic algorithm approach to risk mitigation in project scheduling. *International Journal of Production Economics, 112*(1), 202–216. https://doi.org/10.1016/j.ijpe.2006.08.027

[49] 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. https://doi.org/10.1016/j.ijpe.2007.06.006

[50] Popa, E. M., & Marcut, I. G. (2008). ASM and evolutionary algorithm for economic optimization of project

risk management. In *WSEAS International Conference* (pp. 1–4). Sofia, Bulgaria.

[51] Gonen, A. (2011). Optimal risk response plan of project risk management. In *2011 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 969–973). IEEE. https://doi.org/10.1109/IMWS.2011.6115292

[52] Fang, C., Marle, F., & Zio, E. (2011). An integrated framework for the optimization of project risk response plan under resource constraints with genetic algorithm. In *2011 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering* (pp. 856–861). IEEE. https://doi.org/10.1109/ICQR2MSE.2011.5976743

[53] Fang, C., Marle, F., Xie, M., & Zio, E. (2013). An integrated framework for risk response planning under resource constraints in large engineering projects. *IEEE Transactions on Engineering Management, 60*(3), 627–639. https://doi.org/10.1109/TEM.2013.2242078

[54] Zhang, Y. (2016). Selecting risk response strategies considering project risk interdependence. *International Journal of Project Management, 34*(5), 819–830. https://doi.org/10.1016/j.ijproman.2016.03.001

[55] Zhang, Y., & Zuo, F. (2016). Selection of risk response actions considering risk dependency. *Kybernetes, 45*(10), 1652–1667. https://doi.org/10.1108/K-05-2016-0096

[56] Soofifard, R., & Bafruei, M. K. (2016). Fuzzy multi-objective model for project risk response selection considering synergism between risk responses. *International Journal of Engineering Management and Economics, 6*(1), 72–92. https://doi.org/10.1504/IJEME.2016.079838

[57] Soofifard, R., & Bafruei, M. (2017). An optimal model for project risk response portfolio selection (P2RPS). *Iranian Journal of Management Studies.*

[58] Naji, H. I., & Ali, R. H. (2018). Risk response selection in construction projects. *Civil Engineering Journal, 3*(12), 1208–1221. https://doi.org/10.28991/cej-030950

[59] Marchwicka, E., & Kuchta, D. (2017). Modified optimization model for selecting project risk response strategies. *Operations Research and Decisions, 27,* 1–15.

[60] Soofifard, R., & Gharib, M. (2017). A new approach to project risk responses selection with inter-dependent risks. *International Journal of Engineering – Transactions B: Applications, 30*(5), 720–728.

[61] Cheraghi, E., Khalilzadeh, M., Shojaei, S., & Zohrehvandi, S. (2017). A mathematical model to select the risk response strategies of the construction projects: Case study of Saba Tower. *Procedia Computer Science, 121,* 609–616. https://doi.org/10.1016/j.procs.2017.11.080

[62] Ghassemi, A., & Darvishpour, A. (2018). A novel approach for risk evaluation and risk response planning in a geothermal drilling project using DEMATEL and fuzzy ANP. *Decision Science Letters, 7*(3), 225–242. https://doi.org/10.5267/j.dsl.2017.10.001

[63] Zuo, F., & Zhang, K. (2018). Selection of risk response actions with consideration of secondary risks. *International Journal of Project Management, 36*(2), 241–254. https://doi.org/10.1016/j.ijproman.2017.11.002

[64] Wu, D., Li, J., Xia, T., Bao, C., Zhao, Y., & Dai, Q. (2018). A multiobjective optimization method considering process risk correlation for project risk response planning. *Information Sciences, 467,* 282–295. https://doi.org/10.1016/j.ins.2018.07.013

[65] Rahimi, Y., Tavakkoli-Moghaddam, R., Iranmanesh, S. H., & Vaez-Alaei, M. (2018). Hybrid approach to

construction project risk management with simultaneous FMEA/ISO 31000/evolutionary algorithms: Empirical optimization study. *Journal of Construction Engineering and Management, 144*(6), 04018043. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001486

[66] Shoar, S., & Nazari, A. (2019). An optimization framework for risk response actions selection using hybrid ACO and FTOPSIS. *Scientia Iranica, 26*(3), 1763–1777.

[67] Jannadi, O. A., & Almishari, S. (2003). Risk assessment in construction. *Journal of Construction Engineering and Management, 129*(5), 492–500. https://doi.org/10.1061/(ASCE)0733-9364(2003)129:5(492)

[68] Cervone, H. F. (2006). Project risk management. *OCLC Systems & Services: International Digital Library Perspectives, 22*(4), 256–262. https://doi.org/10.1108/10650750610706970

[69] Aven, T., Vinnem, J. E., & Wiencke, H. (2007). A decision framework for risk management, with application to the offshore oil and gas industry. *Reliability Engineering & System Safety, 92*(4), 433–448. https://doi.org/10.1016/j.ress.2005.12.009

[70] Dikmen, I., Birgonul, M. T., & Han, S. (2007). Using fuzzy risk assessment to rate cost overrun risk in international construction projects. *International Journal of Project Management, 25*(5), 494–505. https://doi.org/10.1016/j.ijproman.2006.12.002

[71] Cagno, E., Caron, F., & Mancini, M. (2007). A multi-dimensional analysis of major risks in complex projects. *Risk Management, 9*(1), 1–18. https://doi.org/10.1057/palgrave.rm.8250014

[72] Zeng, J., An, M., & Smith, N. J. (2007). Application of a fuzzy based decision-making methodology to construction project risk assessment. *International Journal of Project Management, 25*(6), 589–600. https://doi.org/10.1016/j.ijproman.2007.02.006

[73] Zhang, H. (2007). A redefinition of the project risk process: Using vulnerability to open up the event-consequence link. *International Journal of Project Management, 25*(7), 694–701. https://doi.org/10.1016/j.ijproman.2007.02.004

[74] Han, S. H., Kim, D. Y., Kim, H., & Jang, W. S. (2008). A web-based integrated system for international project risk management. *Automation in Construction, 17*(3), 342–356. https://doi.org/10.1016/j.autcon.2007.05.012