Establishing a Budget for Optimal Response Strategies for Risks Categorized into Distinct Groups by using a Mathematical Model and Genetic Algorithm

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ABSTRACT

Construction projects may be subjected to various risks which must be identified, evaluated, and a suitable response to each risk must be determined. The risk response stage is a crucial and significant phase in risk management that requires particular attention. This paper proposes an effective mathematical model for determining the most suitable strategy and action in dealing with both primary and secondary risk events in different risk categories that may arise in a construction project. It also provides a method for estimating or forecasting the anticipated budget for a risk response plan. Another contribution of this study is the development of an innovative approach that combines binary programming with the genetic algorithm. The efficacy of the proposed methodology was examined by its implementation in a real geothermal project. The results demonstrated that the proposed framework serves as a useful tool to tackle the challenges related to the selection and optimization of risk response strategies, as well as setting an appropriate budget for the risk response plan. The suggested model can help decision-makers to assess the variety of viable risk response actions and strategies and arrive at a more well-informed decision.

Keywords-risk management; primary risk; secondary risk; risk responses; modeling; genetic algorithm; construction projects

I. INTRODUCTION

A project is defined as a collection of related activities with clearly established goals. To accomplish these goals, the project must be effectively managed through resource planning, direction, and control [1]. There are always risks involved in carrying out project phases. The risks may increase in difficulty corresponding to the project's level of complexity [2]. The degree of differentiation, interdependence, and influence on project decisions among project components can be considered indicators of project complexity [3]. Project risks are characterized as uncertain external or internal events that could occur during one or more project stages and negatively affect the project's goals [2-6]. The complexity and risks associated with construction projects have increased, as evidenced by recent innovations. In order to capture the interdependencies between risks and their interaction with the project environment, risk analysis and assessment are becoming increasingly complex. The recommendations for improvement fall short in taking into consideration the characteristics of the risks, the interdependencies among them, the complexity of the project environment, or the knowledge of the management team. Risk is now a project attribute rather than a measure of variance [7].

Risk Management (RM) is one of the nine knowledge areas covered by the Project Management Institute (PMI). RM is a systematic process with numerous benefits, including the ability to identify, assess, and manage risks as well as improve construction project management procedures and resource efficiency [8, 9]. In addition to construction projects, RM has been developed and applied in a wide range of industries, including enterprise management, safety, the environment, and health care [10]. RM is a crucial process that needs to be considered in order to identify and evaluate risks, select and implement the best course of action to minimize negative effects and maximize positive effects of risks, and document the risks and the management strategy to serve as a helpful reference in the future [2, 11, 12]. RM comprises four primary stages, as per PMBOK 2008: risk identification, risk assessment and analysis, risk response planning, and risk monitoring and control [13].

Typically, most studies on construction project risks focus on the RM phases of detecting and analyzing risks, rather than emphasizing on improving the Risk Response (RR), although it is an essential element of RM, involving the development of a strategy for addressing risks, generating numerous solutions, and determining appropriate treatments for each risk event. The objective of RR is to minimize the probability of risks and their adverse consequences, maximize the advantages of chances, and eventually achieve the project's objectives [2, 13-16].

The aim of this paper is to develop a mathematical model that can be utilized to identify the most effective course of action for managing both primary and secondary risk events across various risk categories that may occur in a construction project. Moreover, the work entails the prediction or estimation of the expected budget for risk response.

II. RESEARCH STRUCTURE

The research methodology comprises a theoretical and a practical part. The theoretical part encompasses an introductory exploration of risk and RR, along with a review of relevant prior studies. The practical part encompasses the steps involved in developing the mathematical model, gathering data, and implementing the model through the use of the Genetic Algorithm (GA) to attain the intended research objective. These two components are crucial for achieving the research purpose, which is to predict a suitable RR budget. Figure 1 shows the research methodology and Figure 2 illustrates the practical features.

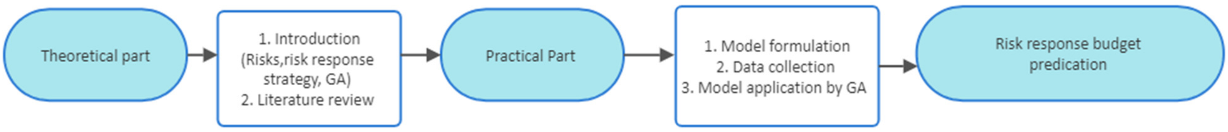

Fig. 1. Research methodology.

III. RISK DEFINITION AND CATEGORIES

Risks are always present when project phases are being carried out, and the complexity of a project could make them more challenging. The complexity of a project can be determined by its inherent nature, characteristics, and requirements. In order to get a comprehensive understanding of risks and the significance of addressing their impacts, many scholars have thoroughly examined threats and provided their own definitions, as outlined below:

- Risk is the potential for financial loss or gain, physical harm, or delay as a result of the unpredictability of a given course of action [17].
- Risk is the potential for losses in a project that could prevent it from succeeding [18-20].
- Risk is the likelihood that something undesirable will happen to the project [4, 21].
- Risk refers to an unpredictable occurrence that has the potential to increase project costs, cause delays, and compromise the quality standards [8, 9].
- Risks are circumstances that could have a negative impact on the project's goals. They can be related to the project's technical, commercial, or operational aspects at any stage of a construction project [5-6].
- Project risk is an unforeseen circumstance that could have a favorable or unfavorable effect on one or more project goals, including budget, scope, quality, and timing [22-24].
- Risk refers to the likelihood of encountering any possible problems in the future that might disrupt the project plan, resulting in deviations from the scheduled timeline [12].
- Risk is an external or internal event that could arise during one or more of the phases of a construction project and have a negative impact on meeting project requirements and objectives [2].

The aforementioned definitions are employed to elucidate and characterize the primary risks that may be addressed via the implementation of an appropriate response plan. However, the phrase "secondary risks" refers to the risks that may arise as a direct result of carrying out a primary Risk Response Action (RRA). Secondary risks, like primary risks, should be handled using a secondary RRA when they are identified and analyzed. Furthermore, various groups of risks can be identified based on their sources, effects, and project activities, including [24-28]:

- Internal and external risks.
- Acceptable and unacceptable risks.
- Risks that can be easily controlled and risks that are difficult to control.
- Risk discipline incorporates all types of risks, including technical, environmental, logistical, socio-political, financial, and management related risks.

IV. LITERATURE REVIEW

In the subject area of RR to projects, Chapman (1979) was the first to develop a methodical technique utilizing a Work Breakdown Structure (WBS) to analyze, evaluate, and address risks [16, 29]. Generally, researchers try to discuss, comprehend, plan, and develop an appropriate strategy for the RR stage in various project kinds. One of the significant approaches that has been previously put forth and suggests various models to be used in managing the RR plan in construction projects is the optimization modeling approach.

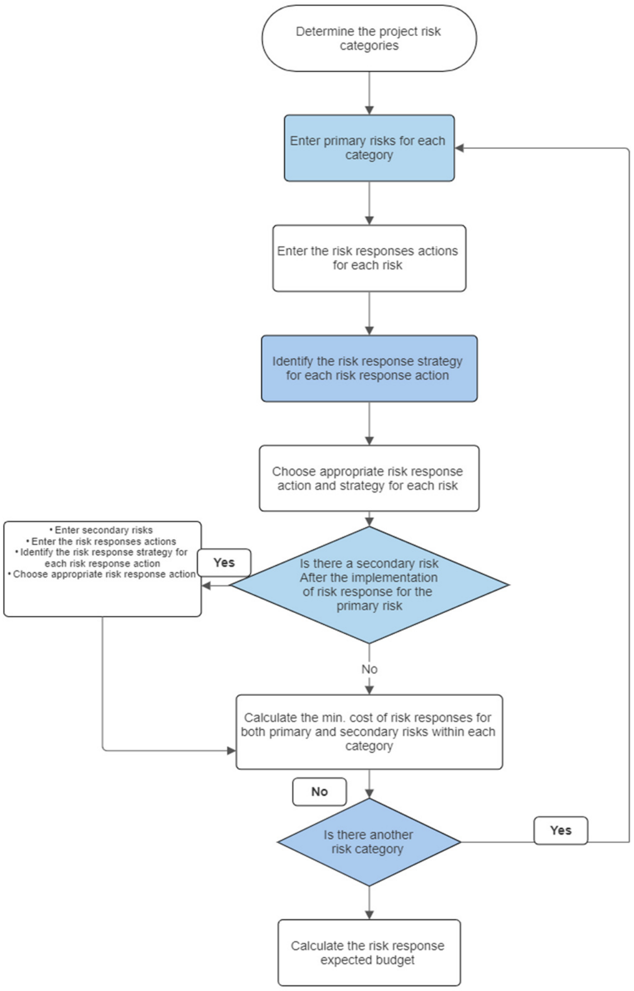

Fig. 2. Steps of risk response budget prediction.

RR strategies were separated into two categories in [1]: (a) Prevention and (b) Adaptation. In order to help managers choose the least expensive course of action (prevention or adaptation) to reduce risks to a manageable level, the authors constructed a mathematical model. Response costs, risk controllability, and project characteristics should all be considered when selecting a strategy. Authors in [29] built a mathematical model to select RR strategies of complex construction projects and identified risks using ISO 31000 and the Failure Mode and Effects Analysis method. The objective of the study was to maximize the effectiveness of each response to the estimated risks. Through their study, the Saba tower project's efficiency increased whereas delays and failure costs were reduced. Authors in [30] attempted to control and explain the uncertainties, pinpointing the causes of RR failure, and employing optimization techniques to determine the most effective RR approach. A mathematical model was developed in [22] to assess the RR efficacy in a quantitative manner. The RR effectiveness was calculated using the probability distribution of the number of days that elapsed after the RR was implemented. A multi-objective Binary Integer Programming (BIP) model was proposed to handle the selection of the most suitable response for each risk event. Authors in [15] analyzed risk interactions and concluded that it is a valuable criterion. The risk structure matrix was utilized to assess the relationships among threats. Authors in [31] applied fuzzy theory, the Analytical Network Process (ANP), and the Decision-making Trial and Evaluation Laboratory (DEMATEL) to weigh risks and responses employing BIP. The model objective function maximizes the value of the response actions. All possible response strategies and secondary risks linked to geothermal drilling projects were considered in this study. An optimization framework comprising three techniques—fuzzy TOPSIS, ant colony optimization, and multi-criteria decision-making—was proposed in [32] for the selection of RR actions. The presented framework covered risk, management standards and characteristics, risk interactions, and the effects of risks on project goals. In order to offer answers and assist the project managers in making decisions that support and achieve the project's objectives, this study seeks to complete the task left by previous researchers. The framework that will be applied when creating a model to ascertain the most economical response plan to possible risks is known as the optimization approach.

V. RISK RESPONSE STRATEGIES AND APPROACHES

Once risk events have been identified, examined, and evaluated, they must be managed through a relevant plan in order to remove or minimize their impact on the success of the project. Several RR strategies that can be followed are [2, 23, 27, 33]:

- Avoidance strategy is putting into action a different plan or activity that carries no risk while concentrating on achieving the project's goals.
- Acceptance strategy is carrying out the task as intended and acknowledging the potential risks.
- Mitigation strategy is implementing the necessary measures to lessen the chance, seriousness, and consequences of risks.
- Transfer strategy is transferring the responsibility of work that entails risk to a third party.
- Sharing is the strategy where several partners will be in charge of handling the risk.
- Removing strategy is eliminating the causes of the risks in order to achieve risk elimination.

The RR phase of the RM process has drawn more attention during the recent years. Thus, efforts to suggest different approaches for managing risks have been made. As indicated in Table I, the RR approaches to help choose the best course of action for addressing risks have been divided into four groups.

VI. GENETIC ALGORITHM IN RISK MANAGEMENT

GA is an algorithm inspired by evolutionary biology, utilizing the principles of natural selection. GA has been employed in construction projects to effectively manage intricate, multi-modal problems and enhance project management by producing solutions that are approximately optimal [40, 41].

TABLE I. RISK RESPONSE APPROACHES

Approach	Approach concept	Ref.
Zonal	This is an approximate methodology for selection of RR strategies, and it depends on: The weighted probability of both internal and external project risks, the degree to which risks are distinctive to the project, and the ability to control them.	[35, 36]
Trade off	This approach is formulated by considering the project needs and the manager's choices on risk-related variables such as cost, duration, quality, and chance of success.	[38, 39]
Work breakdown structure	This methodology relies on both project and RM. The decision-making process for choosing an RR strategy is related to the WBS analysis and the risk identification process.	Chapman (1979) as cited in [34]
Optimization model	The challenge of selecting an RR strategy is resolved via the use of the mathematical optimization mode.	[1, 4, 38]

GA has three fundamental operations: reproduction (selection), crossover, and mutation. Darwinian natural selection is dependent on the process of reproduction, where the crossover mechanism divides a parent string into segments and replaces them with other ones. Mutation is a process that guarantees variety within a population [42]. GA has several benefits, including simplicity in terms of concepts, wide applicability, the ability to combine different approaches (hybridization), resilience to dynamic changes, and adaptability. It has the ability to resolve non-linear problems in continuous, hybrid, or constrained search domains without imposing any mathematical prerequisites. Optimization issues make use of evolutionary computation approaches, which include the assessment of the objective function [43]. GA is a satisfactory choice for handling many RM issues in general, and RR modeling in particular. Authors in [44] established a mathematical model to address the project scheduling under the presence of risk. The model has two objective functions: (1) minimizing the expected makespan and (2) minimizing the anticipated total cost. Using GA to solve this problem was a quick and efficient strategy. Authors in [45] examined the issue of project delay caused by random disruptions to specific tasks, seeing it as an optimization problem that requires further development. They employed the GA to determine the pivotal tasks which involve the highest risk of project delay. In this study, GA was chosen to solve the problem of selecting the optimal RR in construction projects, with the goal of minimizing the cost of RR.

VII. MODEL FORMULATION

The RR strategy includes the options of risk avoidance (V), risk acceptance (A), risk mitigation (M), risk transferring (T), risk sharing (S), and risk removing (R). The overall expense associated with executing these strategies, known as the Total RR Cost for the project (TRRCp), is determined by aggregating the expenses linked to each category of response: risk-avoidance cost (Cv), risk-acceptance cost (Ca), risk-mitigation cost (Cm), risk-transferring cost (Ct), risk-sharing cost (Cs), and risk-removing cost (Cr). The cost of RR techniques should be determined for each individual action. Table II provides a description of each parameter utilized in the proposed model. The model constraints include the following:

- Fitness (cost) Constraint:

  Fitness = total cost = $\sum_{selected\ respons} PC + SC$ (1)

- Strategy Constraints:

$$x_{ij} + x'_{ij} \leq 1 \quad (2)$$

$$x_{ij} + x'_{ij} = 1 \quad (3)$$

$$x_{ij} - x'_{ij} \leq 0 \quad (4)$$

The objective function will be to minimize the total cost of the implementation of the RR strategy for each category and calculate the TRRCp .

$$\text{Min RC}_{\text{G}} = \sum_{e=1}^{E}\sum_{i=1}^{6} PC_{ej}\, x_{ij} + \sum_{e=1}^{E}\sum_{i=1}^{6} SC_{ej}\, x_{ij} \quad (5)$$

$$\text{TRRCp} = (\sum_{e=1}^{E} c_a + \sum_{e=1}^{E} c_v + \sum_{e=1}^{E} c_m + \sum_{e=1}^{E} c_t + \sum_{e=1}^{E} c_s + + \sum_{e=1}^{E} c_r \quad (6)$$

TABLE II. PARAMETER'S DESCRIPTION

Parameter	Description
Ge	(G) risk category, *e*=1,……,*E*
PRej	Primary risk event, *j*=1,…..*n*
SRek	Secondary risk, *k*=1,…..*z*
S_i	Set of RR strategies where *i*=1,….,6 or *m* if RR actions are considered
PC_{eij}	Cost for the implementation of the *i*-th primary RR.
SC_{eik}	Cost for the implementation of the *i*-th secondary RR.
X_{eij}	Decision variable, it is equal to 1 if the *i*-th RR strategy for the (*j*-th) risk in the (*e*-th) activity, otherwise it equals zero
RC	Total cost of response strategies(actions)
TRRCp	Total RR cost
Min RC_G	Minimum RR cost for each risk category.

VIII. DATA COLLECTION

To verify the viability of the proposed RR selection model, the model is applied to an actual case study. The data used to validate the reliability of the model came from the published research of [31]. Geothermal energy green is a renewable and tidy form of energy. Wells are drilled underground to access the geothermal energy reservoir, frequently descending hundreds of meters. It is a challenging procedure, given that it involves breaking the ground and extracting the rock. The project's ultimate goal is to obtain sufficient resources for exploitation through geothermal drilling. The risk categories are listed in Table III along with the risks that are expected to occur. Table IV displays the available RR actions for each activity and the possible secondary risks that may occur due to the implementation of these RRs. Authors in [31] identified 12 significant risks that could have an impact on the project's core functions, and 19 possible actions that could address the primary risks taking into account the cost of the potential secondary risks as observed in Table V. The data in Tables III-V are derived from [31].

TABLE III. RISKS AND RISK CATEGORIES

Risk category	Primary risk ID	Primary risk description
Technical risks	PR2	Collapsed casing
	PR5	Drill string breakdown
	PR6	Equipment lost or jammed in pit
	PR9	Circulation loss
	PR10	Non-functioning well
Management risk	PR1	Bureaucratic government system
	PR3	Delayed equipment delivery
Natural risks	PR4	Dissolved gas in formation water
	PR7	Severe weather circumstances
	PR8	High salinity in formation water
	PR11	High level of pressure on the formation
	PR12	Harmful gases (such as H_2S) discharged from the well

TABLE IV. RISK RESPONSE ACTIONS AND STRATEGIES

Response actions	Description	Strategy
A1	Implementing inhibitors	M
A2	Limit control for injection pressure	M
A3	Developing a coating to safeguard the drill pipe	M
A4	Enhancing casing design	M
A5	Constructing a sidetrack	M
A6	Additional investigation of the field prior to advancements	M
A7	Employing cautious, knowledgeable, and proficient site labor	M
A8	Engineering improvement of the wellhead systems	M
A9	Enhancing the cleansing of holes with chemicals	M
A10	Enhancing HSE conditions	M
A11	Maintaining a minimal bottomhole pressure	M
A12	Establishing a positive relationship with the government and NGOs	M
A13	Construction methods modified in accordance with the local weather	V
A14	Developing an exhaustive training program	M
A15	Offering steerable rotary systems	M
A16	Acquiring a guarantee fund or insurance	T
A17	Raising the accuracy of order tracking	M
A18	Utilizing a degasser	M
A19	Utilizing chemicals and water to dissolve salts	M

IX. MODEL APPLICATION

The proposed model was solved deploying the GA, and the RR plan with the lowest cost per risk category was chosen. The model estimates that $2555 will be needed to implement the RR plan in order to address the project's risks. The results are depicted in Table VI.

The proposed model was applied to the specified project, incorporating the risks identified from various categories through the utilization of GA. Consequently, distinct results were achieved for each risk, such as the effect of R3, which is the delay in delivering equipment to the site that belongs to the management risks category. To respond to this threat, the A17 response can be implemented. It was evaluated against alternative action A12 response considering the cost criteria, while also considering the presence of secondary risks. Ultimately, the A17 treatment was chosen. The selected RR action is a subordinate component of the mitigation strategy, which is one of the six techniques outlined above for dealing with risks. This methodology was implemented for every risk category and for all potential threats, subsequently proposing an estimated budget for the efficient management of risks. This method may be characterized as a beneficial, efficient, and uncomplicated tool for decision makers.

TABLE V. RISK RESPONSE COSTS

Primary risk ID	Related RR action	Primary cost	Secondary risk ID	Cost
PR1	A12	180	SR12	60
PR1	A16	320	-	0
PR2	A4	360	-	0
PR2	A7	280	-	0
PR2	A15	680	SR15	80
PR3	A12	180	SR12	60
PR3	A17	140	-	0
PR4	A6	240	-	0
PR4	A18	215	SR18	30
PR5	A7	280	-	0
PR5	A14	190	-	0
PR5	A16	320	-	0
PR6	A1	230	SR1	45
PR6	A5	570	SR5	180
PR6	A7	280	-	0
PR6	A9	200	SR9	50
PR7	A7	280	-	0
PR7	A10	160	-	0
PR7	A13	350	SR13	100
PR8	A1	230	SR1	45
PR8	A6	240	-	0
PR8	A19	250	SR19	20
PR9	A4	360	-	0
PR9	A9	200	SR9	50
PR9	A11	220	SR11	25
PR10	A5	570	SR5	180
PR10	A6	240	-	0
PR10	A16	320	-	0
PR11	A2	170	-	0
PR11	A4	360	-	0
PR11	A6	240	-	0
PR11	A8	430	-	0
PR12	A1	230	SR1	45
PR12	A3	370	SR3	30
PR12	A6	240	-	0
PR12	A10	160	-	0

TABLE VI. THE RESULT

Risk category	Primary risk ID	RR actions	Min RC	Strategy
Technical risks	PR2	A7	1205	M
	PR5	A14		M
	PR6	A9		M
	PR9	A11		M
	PR10	A6		M
Management risks	PR1	A12	380	M
	PR3	A17		M
Natural risks	PR4	A6	970	M
	PR7	A10		M
	PR8	A6		M
	PR11	A2		M
	PR12	A10		M

X. CONCLUSION

An optimization-based model for choosing the best risk response tactics and actions was presented in this paper. The proposed model was solved applying the genetic algorithm to find the best possible set of response actions that would minimize the cost of risk management while accounting for secondary risks. The efficacy of the suggested framework was illustrated by its implementation in an actual geothermal project. The following is a summary of the proposed method's primary contributions:

- The available risk response strategies (transfer, mitigation, acceptance, sharing, removing, and avoidance) were all taken into account.
- The secondary risks and their expenses, caused by responses, were considered.
- The proposed framework can be utilized in a wider range of construction projects due to the characteristics of the genetic algorithm.
- The genetic algorithm in conjunction with the optimization technique is a helpful tool for addressing the challenge of optimizing the risk response problem.
- Limitations and constraints considerably affect the process of designing the risk response phase, appropriately projecting the budget for this stage, as well as addressing and managing risks. These issues encompass insufficient communication among project stakeholders, the presence of unqualified team leaders, and the inadequacy and absence of comprehensive documentation concerning the risk management process in completed or ongoing construction projects that extend from risk identification and assessment to risk response planning.
- In order to highlight the strength, and to reduce the weakness and limitation of the proposed model, it is recommended to take additional case studies from different types of construction projects, apply the suggested approach according to the project activities and risk categories, or use another technique instead of GA.

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