Journal of Contemporary Issues in Business and Government Vol. 27, No. 3, 2021
https://cibg.org.au/
P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2021.27.03.351

Optimization of Risk Response Strategy for Primary, Secondary and Residual Risks Encountered in Oil and Gas Projects Considering Two Dimensions: Time and Cost

MARYAM TABATABAY ASL[1*], SAEEDEH TABATABAY ASL[2]

[1*]Management Department, Islamic Azad University, Semnan Branch, Semnan, Iran.
[2]Management Department, Islamic Azad University, Central Tehran Branch, Tehran, Iran.
*Corresponding Author
Email ID: [1]maryamtabatabay520@gmail.com

Abstract: Any risk response strategy (RRS) tends to change the risk status in the project. Trivially, the response is designed to improve the risk status, but it may not necessarily work as planned or the outcome may extend beyond the effect of the specific risk for which the response was planned. There are cases where implementing a response eliminates the risk but reciprocally arises other risks for the project. Most of the existing RRSs are focused on eliminating the primary risks without considering the secondary and residual risks that may arise during the implementation stage. This is while secondary risks can be a direct result of performing an activity that is originally designed to respond to a primary risk. It is then evident that determining an appropriate set of measures for responding to risks plays an important role in the success of a project. In addition, it is important to note that a secondary risk that arises from implementing an RRS to a primary risk must be treated in a similar way to the primary risk itself, because, similar to primary risks, secondary and residual risks impose negative impacts on the project performance and hence must be responded adequately. Sometimes, responding to a primary risk results in such a serious secondary risk that makes the situation even worse than it was before implementing the response to the primary risk. Therefore, considering secondary and residual risks along with the primary risks is a vital step toward successful implementation of a project. In this study, an optimization model was proposed for RRS selection against primary and secondary risks. Compared to the model proposed by Zhao (2018), the present work offers a core novelty that prevents the selection of predefined strategies while considering two dimensions when formulating responses to primary and secondary risks, namely time and cost. Moreover, as a metaheuristic method, genetic algorithm was herein used to solve large-scale problems.

Keywords: Response strategy optimization, Primary and secondary risks, Time and cost.

PROBLEM DEFINITION

Continuous and dynamic management of risk throughout the project life cycle, from the beginning of the initial phase to the end of the final phase, is a basic requirement for success in any project-oriented organization. To identify and effectively manage risks at all stages of the project, intelligent decisions must be made at all levels of the organization. Risks can be there right from the beginning of a project. This implies that running a project without an active focus on risk management can lead to serious problems arising from non-managed risks. By definition, risk is an uncertain event that, once occurred, imposes positive/negative impact(s) on at least one of the project objectives. The positive risks are what we call opportunities while negative risks are generally referred to as threats (PMBOK, 2017). When planning a project, the project manager (PM) has little information about the risks associated with each activity and hence possible time delays, excessive costs, and quality reductions that may occur should the risks come true. According to Wang (2019), failure to respond to a risk properly attenuates the effectiveness of risk identification and assessment. In practice, however, the significance of risk response strategy (RRS) is yet to be adequately regarded, as compared to the risk identification. Five generally strategies may be adopted when responding to a threat; these include avoidance, transfer, mitigation, acceptance, and upgrading the decision-making level (PMBOK, 2017). Following different objectives, PMs may opt for one or more of these five strategies depending on project conditions, severity of risks, availability of resources, and other factors related to the project objectives. In particular, risk avoidance refers to the elimination of risk-associated threats, while mitigation aims to reduce the likelihood of the occurrence or impact of the risk down to an acceptable level (Kalantari, S, et al, 2020). Risk avoidance is usually practiced by eliminating all activities associated with that risk from the core plan. Despite its effectiveness, risk avoidance may lead to particular complexities in project management because new risks are created by new activities. In contrast, risk mitigation is seemingly more practical and tries to attenuate the risk by selecting and implementing a proper set of measures in response to it. Therefore, selecting the right response to a risk reduces the associated threats to the project activities (Arasteh, S, et al, 2018) (Chapnevis, A, et al, 2020).

Any RRS tends to change the risk status in the project. Trivially, the response is designed to improve the risk status, but it may not necessarily work as planned or the outcome may extend beyond the effect of the specific risk for which the response was planned. There are cases where implementing a response eliminates the risk but reciprocally arises other risks for the project (Masoumnezhad, M, et al, 2020). The risks arisen from implementing a risk response are called secondary risks. It is necessary to identify the secondary risks arising from responding to primary risks of the project and to assess them in a similar way to that of primary risks. To this end, one should predict the project risk status after implementing a response to a primary risk. For example, consider the risks involved in driving to an important meeting in an unforeseen city. The car may break down, the driver may get lost, there may be no parking space for the car, and the traffic may lead to some delay, and so on. By alternatively taking a train instead of the car, one may avoid these risks. This response, however, creates a new set of risks including possible cancellation of the train schedule, unexpected delays, and lack of transportation from the train station to the place of meeting. In this example, one must evaluate the secondary risks associated with traveling by train against the uncertainties associated with driving by car to determine whether the response is worth implementing. In addition to secondary risks, residual risk is considered in this work. It is the risk that remains despite deploying the control factors to mitigate the risk. That is, with the primary and secondary risks identified and managed, the risk that remains uncontrolled as it cannot be identified primarily is referred to as residual risk. These are risk components that persist even after implementing avoidance, mitigation, and/or transfer measures.

In this work, optimization of RRS for primary, secondary, and residual risks is considered in Nardis Oil and Gas Company (NOGC). Mastering in imports and procurement of heavy equipment, the company intends to plan the transportation and installation of an 800-ton tower. To do this, they must prepare plans for carrying out 19 different sets of activities in such a way that favors the best possible conditions at minimum possible level of risk.

LITERATURE REVIEW

In their research, Denisova et al. (2021) evaluated project implementation plans in presence of associated risks. They considered two alternative methods for planning: network modeling and integer programming. It is assumed that project risk is associated with a positive or negative event (or a combination of them) that may occur during the course of project. Different scenarios may develop depending on the conditions under which a hazardous event occurs. The level of risk associated with each scenario is then estimated based on the projected values of the financial parameters of the project. Scenario testing is a common practice for each and any risk-mitigating method. The method described in this work was reviewed using a well-known example of an infrastructure project where a gas pipeline segment was placed on the seabed.

Khalilzadeh et al. (2021) presented a new approach to the so-called failure mode and effects analysis (FMEA) based on fuzzy multi-criteria decision-making (MCDM) and multi-objective planning model for risk assessment in planning stage for the oil and gas construction projects (OGCPs) in Iran. This was done in several stages. First, 19 major health, safety and inspection (HSE) risk factors in the OGCPs were classified into six categories using the Delphi technique. These factors were identified by reviewing the project documents, checklist analysis, and consulting with experts. The factors were then weighted using fuzzy SWARA before using the FMEA and PROMETHEE methods to have them prioritized. Finally, a multi-objective binary linear programming model was developed for selecting appropriate RRS, with an augmented e-constraint method (AECM) employed.

Zhang et al. (2020) proposed a method based on case-specific analysis and fuzzy optimization to support decision-making in response to project risks. The main steps of the method included (1) formulating risk response alternatives (RRAs) based on case-specific analysis and (2) determining an optimal set of RRAs using a fuzzy optimization model. Based on this method, project managers (PMs) can identify RRAs and further determine the optimal set of RRAs. In conclusion, this article offered particular managerial recommendations and implications. First, in order to respond to a future risk in a better way, organizations were recommended to consider a long-term perspective and record documents of all historic projects that have been once managed. Second, given the necessity of adopting an RRA derived from alternative historical cases to the existing conditions, compatibility costs must be accounted for when allocating funds to RRA selection.

Choi et al. (2020) believed that complex projects suffer from numerous correlated risk factors. Accordingly, an RRS may not achieve a good risk response if it fails to consider this correlation. In this respect, they tried to provide a model for RRS selection considering this risk correlation using the K-shell decomposition algorithm. They stipulated that, regardless of the risk nature, any RRS considering this correlation is more effective than any other one without considering the correlation. Their results indicated that the effect of risk response increases with the risk response budget, attenuating the growing impact of risk. They further figured out that relative distance between the impacts of RRSs with and without considering the risk correlation follows an initially increasing trend with increasing the budget, but then decreases.

Li Wang et al. (2020) used a simulation model to evaluate RRSs considering risk interplays and used a simulation scheme to assess decisions, with the optimization problem solved using genetic algorithm (GA).

Zhang et al. (2020) used a hybrid DEMATEL-network analysis method to weigh the risks of abandoning a train at the railway station and identified RRSs using the Delphi technique, with the TOPSIS then utilized to rank the RRSs.

Piedade et al. (2020) tried to optimize crisis response time. Examining different types of crisis and their propagation at Lisbon Airport, they used an optimization model to minimize the crisis response time and cost.

In their work, Yang et al. (2020) developed a conceptual model of risk response by identifying sources of environmental risk, stressors, endpoints and relevant response mechanisms. They further considered an improved TOPSIS model based on the Canberra distance and a hybrid weighting method based on analytic hierarchy process (AHP) for risk assessment in three sectors, namely agriculture, industry and urban planning. Using their model, they comprehensively investigated the mechanism of occurrence of ecological risk of rivers in semi-arid areas. Results of their comprehensive environmental risk assessment and analysis of stressors showed that the deterioration of water quality (increased concentration of heavy metals in water) and reduced benthos integrity are the two main risk factors that contribute to increased ecological risk within the Wei River watershed, and that this risk can be mitigated by improving the water quality and biotic integrity.

Koulinas et al. (2019) published a research where they investigated the risk at work sites in Greek construction sector using fuzzy network analysis process. The results showed that the proposed framework could serve as a useful tool for decision-makers to estimate a constrained emergency budget with the aim of achieving health and safety at minimum cost.

Cao et al. (2019) proposed a mathematical model to mitigate the cost of risk management and used the particle swarm optimization (PSO) to solve the developed problem. In his research, they examined socioeconomic and technical conditions under the influence of many risks due to uncertain weather. The outcomes showed that the PSO could solve the mitigation problem without any violation of the model constraints. The proposed model could provide proper RRSs (acceptance, mitigation, transfer, or avoidance) to minimize the risk level while keeping the total budget at a minimal level.

Zhao et al. (2018) believed that, in the framework of project risk management, a secondary risk is one that is a direct result of implementing an RRA. Accordingly, it is importance for PMs to consider the impacts of secondary risks when selecting an RRA. In this work, the authors presented an optimization method for addressing the problems associated with RRA selection considering the secondary risks. The proposed optimization model was aimed at minimizing the cost of risks while satisfying the time constraints of the project.

Adelke et al. (2018) investigated the role of the external factors on construction risk management in Nigerian construction companies using partial least squares structural equation modeling (PLS-SEM). Soleh et al. (2018) evaluated appropriate strategies such as early warning, rapid coverage, and rapid recovery in response to potential risks.

Zhang et al. (2016) published a two-objective model for selecting the best RRS considering risk correlations. In another piece of research, Fattahi et al. (2018) assigned a fuzzy weighted risk priority number to each failure. In this study, a combination of fuzzy AHP (FAHP) and fuzzy MULTIMOORA was employed to weigh FMEA factors and failure modes. The fuzzy MULTIMOORA assigns a weight to a failure based on three criteria, namely time, cost and profit, through fuzzy verbal expressions. Once finished with calculating the fuzzy weighted risk priority number for each failure, corrective measures are taken to eliminate the known failures or mitigate their effects.

Khodeir and Mohamed (2015) identified the greatest risks threatening construction projects in Egypt considering political and social factors. They investigated project management methods and construction risks. Findings of this study provided a reference for project risk management in construction projects under similar conditions.

Taylan et al. (2014) investigated the use of then-modern analytical instruments (e.g. fuzzy AHP and fuzzy TOPSIS) for risk assessment of construction projects and general categories of risk under unknown and uncertain conditions. In this research, construction projects were evaluated based on five primary criteria, including time, cost, quality, safety, and sustainability.

Hwang et al. (2014) analyzed risk management in small-scale construction projects based on status, barriers, and effect of risk management on the project performance. Results showed that the most significant factors affecting proper implementation of risk management in the considered projects include time deficiency, budget deficiency, small profit margin, and economic unviability, among others. Rafindadi et al. (2014) presented another work where they investigated global perception of risk in sustainable construction projects. The objective was to comparatively analyze how different stakeholders understand the risk and how does this understanding affect the project success.

Mousavi (2012) presented a study where he discussed an MCDM technique for responding to risks arising in oil and gas projects (OGPs). This article proposed a then-novel decision-making method in fuzzy domain using the so-called decision tree and TOPSIS methods for evaluating and selecting the best strategies to deal with the project risks. Khalili-Damghani et al. (2012) presented an integrated multi-objective framework for selecting the project portfolio considering profit and risk objectives. To this end, they employed the TOPSIS technique and an efficient variant of epsilon-constraint method. Indeed, the TOPSIS technique was utilized to reduce the MCDM problem into a two-objective optimization problem while the epsilon-constraint method was used to generate non-dominated solutions on the Pareto front of the two-objective problem.

PROBLEM DESCRIPTION

Interpretation refers to describing the data in a meaningful way. Description of raw data is, however, difficult and sometimes impossible. Therefore, one must analyze the data before they can be interpreted. In this respect, the analysis means classifying, organizing, processing, and summarizing the data to find answers to the research questions. The purpose of analysis is to reduce and somehow simplify the data into an understandable and interpretable format in such a way that the relationships of various variables related to the research problem can be studied. In the course of interpretation, based on the analysis results, inferences are developed about the studied relationships and conclusions are drawn regarding these relationships. An interpreter then is in search of meanings and their applications. In this research, GAMS software was utilized for data analysis.
As an objective function, total project cost minimization includes three types of constraints:

1. Time constraint.
2. Cost constraint.
3. Decision stability constraint.

Finally, by solving the final cost model considering the three constraints, one can achieve appropriate RRSs to the primary and secondary risks.
For this purpose, firstly, information related to each activity was collected from project planning experts. Then, relevant experts were consulted to obtain the required information about primary risks and relevant RRSs. To this end, the experts began by evaluating the probability of occurrence (PO) of each risk. They then make an estimate of the impact of the risk on total cost and completion time of the project in terms of possible loss and delay, respectively. Finally, calculations were done to predict losses and delays with increasing the PO of each risk. In a similar way, secondary risks were treated to estimate their resultant loss and delay. Finally, mathematical modeling was performed with the help of the GAMS software.

MATHEMATICAL MODELING

In order to formulate RRSs for primary and secondary risks, the following mathematical modeling was used.

Indices	
I	Prerequisite activity index
J	Proceeding activity index
l	risk
k	response
Parameters	
$qcost_{il}$	Estimated cost of primary risk l on activity i
$qtime_{il}$	Estimated time of primary risk l on activity i
$ecost_{ilk}$	Cost saving arising from allocating the strategy k to the primary risk l in activity i
$etime_{ilk}$	Time saving arising from allocating the strategy k to the primary risk l in activity i
$caction_{ilk}$	Cost of allocating strategy k to the primary risk l in activity i
$qcosts_{ilk}$	Unforeseen cost of secondary risk l on activity i incurred by implementing the secondary strategy k
$ecosts_{ilk}$	Unforeseen cost saving from secondary risk l on activity i incurred by implementing the secondary strategy k
$qtimes_{ilk}$	Time loss due to unforeseen secondary risk l on activity i incurred by implementing the secondary strategy k
$etimes_{ilk}$	Time saving arising from unforeseen secondary risk l on activity i incurred by implementing the secondary strategy k
$cactions_{ilk}$	Cost of implementing the strategy k to address the secondary risk l on activity i
$ccrash_i$	Crash cost of the activity i
q_i^*	Maximum risk budget for activity i
d_i^*	Maximum acceptable delay for activity i
$dmin_i$	Minimum time required to accomplish activity i
Variables	
y_{ilk}	1 if strategy k is assigned to respond to primary risk l on activity i, 0 otherwise
y'_{ilk}	1 if strategy k is assigned to respond to secondary risk l on activity i, 0 otherwise
x_i	Optimal crash rate of activity i
$drisk_i$	Time for which activity i is at risk
t_i	Time to accomplish activity i

Now, with all variables and parameters of the model defined, let's investigate the objective functions and constraints, as follows:

$$minz_1 = \sum_i \sum_l qcost_{il} + \sum_i \sum_l \sum_k caction_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k ecost_{ilk} * y_{ilk} \quad (1)$$

According to the above equation, estimated cost of risk on each activity and the cost of risk response are summed and the result is subtracted from the estimated cost saving upon responding to the risk. In fact, this equation tends to optimize overall cost of primary risks of the project. Notably, however, the cost of residual risk can be expressed as follows:

$$residual\ risk = \sum_i \sum_l qcost_{il} - \sum_i \sum_l \sum_k ecost_{ilk} * y_{ilk} \quad (2)$$

Equation (3) represents the secondary risk, which is a result of implementing strategies to respond to a primary risk or another. Presenting a second objective function, the following expression seeks to minimize the cost of responding to the secondary:

$$minz_2 = \sum_i \sum_l \sum_k qcosts_{ilk}\, y_{ilk} \quad {}_{il} + \sum_i \sum_l \sum_k cactions_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k ecosts_{ilk} * y'_{ilk} \quad (3)$$

According to the above equation, estimated cost of a secondary risk on each activity and the cost of risk response are summed and the result is subtracted from the estimated cost saving upon responding to the risk. In fact, this equation tends to optimize overall cost of secondary risks of the project. Notably, however, the cost of residual risk can be expressed as follows:

$$residual\ risk = \sum_i \sum_l \sum_k qcosts_{ilk} * y_{ilk} \quad {}_{il} - \sum_i \sum_l \sum_k ecosts_{ilk} * y'_{ilk} \quad (4)$$

The following equation evaluates the crash cost of different activities:

$$minz_2 = \sum_i \sum_l \sum_k qcosts_{ilk}\, y_{ilk} \quad {}_{il} + \sum_i \sum_l \sum_k cactions_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k ecosts_{ilk} * y'_{ilk} \quad (5)$$

With the crashing costs evaluated, all objectives of the model are now well defined. The main goal is to minimize total cost of primary and secondary risks and project crashing.

Constraints of the model are explained in the following. The first constraint contributes to the formation of the problem node network, as follows:

$$t_j \geq t_i + d_i + drisk_i - x_i \ \forall(i,j)$$
$$t_i \leq tdue \ \forall(i) \quad (6)$$

The above constraint considers the time to accomplish different activities. The next constraint sets a maximum allowable delay to each activity, as follows:

$drisk_i \leq\ d_i^* \ \forall(i)$

$$\boldsymbol{drisk_i = \sum_l qtime_{il} - \sum_l \sum_k etime_{ilk} * y_{ilk} + \sum_i \sum_l \sum_k qtimes_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k etimes_{ilk} * y'_{ilk} \quad \forall(l,k)} \quad (7)$$

The above two constraints account for the excessive time required for accomplishing the project upon occurrence of the primary and secondary risks. One can complete these two by the following three constraints:

$$drisk_i \geq 0 \ \forall(i)$$
$$x_i \geq 0 \ \forall(i) \quad (8)$$
$$x_i \leq\ d_i - dmin_i \ \forall(i)$$

The above constraints ensure that the activity crashing time is at least 0 and goes no longer than the difference between normal time of accomplishment and minimum delay for that specific delay. Once finished with the node network forming and time constraints of the problem, the constraints associated with risk costs are expressed in the following:

$$\sum_{l} qcost_{il} - \sum_{l} \sum_{k} ecost_{ilk} * y_{ilk} + \sum_{i} \sum_{l} \sum_{k} qcosts_{ilk} * y_{ilk} - \sum_{i} \sum_{l} \sum_{k} ecosts_{ilk} * y'_{ilk} \leq q_i^* \; \forall(l,k) \quad (9)$$

Constraint (8) limits the budget allocation to keep the costs of primary and secondary risks below the overall budget. Compared to the model proposed by Zhao (2018), the present work offers a core novelty that prevents the selection of predefined strategies while considering two dimensions when formulating responses to primary and secondary risks, namely time and cost. The following two constraints examine the two dimensions (i.e., time and cost) in response to primary and secondary risks:

$$\begin{aligned} ecost_{ilk} + etime_{ilk} * ccrash_i &\geq caction_{ilk} * y_{ilk} \; \forall(i,l,k) \\ ecosts_{ilk} + etimes_{ilk} * ccrash_i &\geq cactions_{ilk} * y'_{ilk} \; \forall(i,l,k) \end{aligned} \quad (9)$$

These two constraints work in such a way that an RRS is selected only if its benefits exceed its implementation costs for primary and secondary risks.
The dependency of primary and secondary risks is herein described by the following expression:

$$y_{ilk} \geq y'_{ilk} \; \forall(i,l,k) \quad (10)$$

The above constraint describes the dependence of the secondary risk on the primary risk; that is, a secondary risk cannot exist unless a primary risk is there.

PROBLEM SOLVING METHOD

Due to the fact that the research is focused on an NP-hard problem, a metaheuristic algorithm was used to have it solved numerically at medium and large scales. The choice of appropriate metaheuristic algorithm is of paramount importance depending on the nature of the problem at hand and solving mechanism of different algorithms.
According to a review of the research literature, population-based nature-inspired algorithms are the most popular metaheuristic algorithms for problem solving. As a well-known algorithm of this class, GA has been efficiently used for solving various problems (Bacao et al., 2005). Therefore, this algorithm was used in this research.

Solution Representation

As mentioned earlier in this research, the binary variables of the problem exhibit similar structures. Accordingly, we began by designing the chromosome representing the strategy k to respond to the primary risk l on activity i. This was done in two steps, as follows:

Activity designation	D1	D2	D3	D4	D5
Risk designation	R1	R1	R1	R1	R1
Assignment	0	1	0	1	0

Figure 1: Assigning primary risk to different activities

As shown in Figure 1, for each chromosome, a primary risk would occur if the relevant assignment takes a value of 1, in which case one must proper strategies must be assigned to the resultant risks, as follows:

Activity designation	D1	D2				D3	D4				D5
Risk designation	R1	R1				R1	R1				R1
Strategy designation	0	K1	K2	K3	K4	0	K1	K2	K3	K4	0
Assignment	0		1	1		0		1	1		0

Figure 2: Assigning strategies to risks

As seen previously, the secondary risk exhibits a similar behavior to the primary risk. But the crashing time of activity i would be a continuous chromosome of integers up to the maximum allowable delay for that activity. Crossover and mutation are the main operators of the GA for offspring generation. The crossover is a process where information of two parents are combined to generate one (or more) new solution (i.e. offspring). In this research, two-point crossover operator was utilized as the main offspring generation mechanism, with the mutation used secondarily. The mutation operator operates by selecting several genes from the chromosomes and exchanging their values. Afterwards, a selection operation is conducted to keep the best parents in each generation for the next generation. The selection strategy, indeed, seeks to generate a new generation that is, on average, better than the current generation in terms of fitness. In this research, random sampling strategy without substitution was used to select the best solutions at each iteration (Deng et al., 2015). The following pseudo-code presents the structure of the GA adopted in the research.

```
Input: fitness function, max no. of iterations, population size, crossover ratio, mutation ratio
Output: the elitist
Initialize a population randomly
Calculate the fitness of population and find elite
 t = 0
 While t ≤ T do
 Perform crossover using two-point crossover operator
 Perform Mutation
 Carry out the replacement strategy and evaluate
 Calculate the fitness and return elite
 t = t + 1
 End
 Final solution ← elite
End
Return Final Solutions
```

Figure 2: Pseudo code of GA

Description of Numerical Example

A company with activities in the field of imports and procurement of facilities related to heavy equipment intends to plan the transportation and installation of an 800-ton tower. To do this, it must plan to carry out 19 different sets of activities in such a way to provide for the best possible conditions at minimum possible risk. These activities are described in Table 1.

Table 1: Activity description and risk description and initial risk response strategy

#	Activity	Normal duration	Risk no.	Risks	Strategy no.	Strategy
1	Selecting a foreign carrier company	14	1	Delays due to inappropriate contractor selection	1	Selecting bidders out of qualified vendor lists
2	Shipping from the manufacturer to the port of origin	3	2	Increased cost of performing the work due to inappropriate contractor selection	2	Pre-evaluation of bidders
3	Loading the tower on the ship Sea transport	4	3	Delays due to delay in tendering process	3	Considering technical appraisal scores when determining the winner
4	Selecting a land transport contractor Unloading the tower from the ship at the destination port	30	4	Increased cost of work due to delay in tendering process	4	Employing experienced personnel
5	Transporting the tower from the port to the installation site workshop	14	5	Damage to equipment due to road accidents	5	Preparing clear and flawless tender documents
6	Selecting an installation contractor	2	6	Damage to equipment due to maritime accidents	6	Holding Q&A sessions
7	Unloading the tower near the installation site	7	7	Delay due to atmospheric effects	7	Buying insurance coverage for equipment transport
8	Selecting an installation contractor	14	8	Delay due to breakdown of ship lifting equipment	8	Suitable leaching
9	Unloading the tower near the installation site	1	9	Damage to equipment due to breakdown of ship lifting equipment	9	Using professional fleet for escort
10	Preparing a lifting plan and obtaining its approval	7	10	Damage to equipment due to human error	10	Purchasing or leasing the required technology
11	Examining competency certificates of human agents	4	11	Delay due to inadequate access to roads	11	Buying insurance coverage for whole installation risk
12	Examining competency certificates of cranes and lifting tools	6	12	Increased cost due to inadequate access to roads	12	Holding sensitive operation maneuvers

13	Padding and making the necessary preparations on the foundation surface	4	13	Delay due to time-consuming approvals	-	-
14	Holding a briefing and a coordination meeting for the actors involved	1	14	Involvement of lowly skilled personnel due to poor qualification by inspection team	-	-
15	Performing lifting operations and placing the tower on the foundation	1	15	Delay due to involvement of lowly skilled personnel	-	-
16	Making adjustments and shim placement	1	16	Increased cost due to involvement of lowly skilled personnel	-	-
17	Closing and torquing the beads	1	17	Delay due to human errors	-	-
18	Obtaining installation confirmation	1	18	Increased cost due to human error	-	-
19	Molding and grouting	2	19	Use of inappropriate equipment due to poor evaluation by the inspection team	-	-
-	-	-	20	Increased time due to equipment failure	-	-
-	-	-	21	Increased cost due to unavailability of technology	-	-
-	-	-	22	Delay due to unavailability of technology	-	-
-	-	-	23	Equipment damage due to operational error	-	-
-	-	-	24	Damage due to non-calibrated equipment	-	-

The defined activities shall be performed in a particular order, as demonstrated in the form of a node network in Figure 3. In fact, this network is based on the way each activity requires its preceding and proceeding activities.

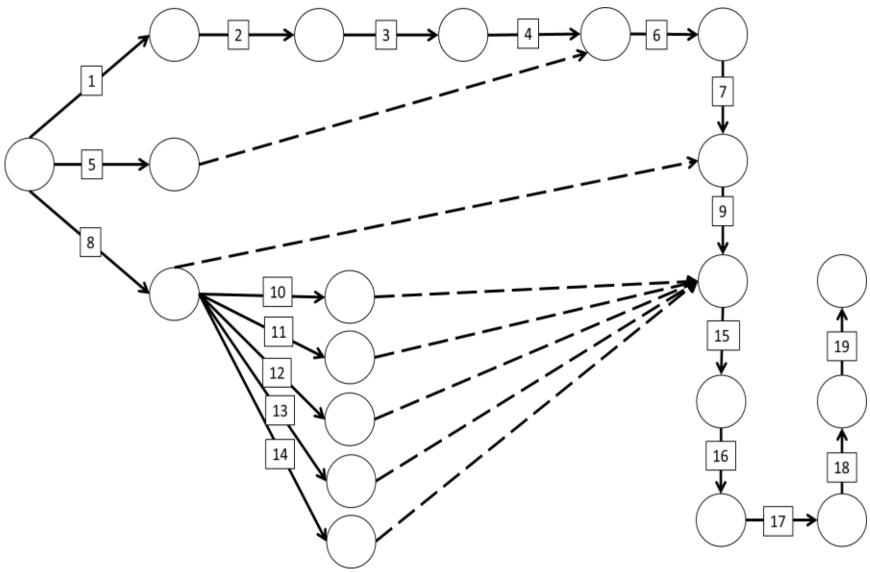

Figure 3: Node network demonstrating different activities for transportation and installation of the 800-ton tower

Continuing with this research, we explain the research parameters before proceeding to the solutions. This is started by explaining the time and cost effects of the risks on the defined activities. This has been done based on the information collected from the NOGC.

Table 2: Time and cost effects of risks on defined activities

Activity no.	Crash cost	Risk no.	PO of risk	Severity (cost)	Severity (time)	Financial impact	Time impact
1	0.02	1	0.4	0	10	0	4
		2	0.4	30	0	12	0
		3	0.5	0	14	0	7
		4	0.5	14	0	7	0
2	0.08	5	0.05	100	90	5	4.5
		7	0.05	5	3	0.25	0.15
		11	0.15	0	14	0	2.1
		12	0.15	10	0	1.5	0
		17	0.01	0	2	0	0.02
		18	0.01	2	0	0.02	0
3	M	8	0.01	0	2	0	0.02
		9	0.01	100	90	1	0.9
		10	0.01	10	10	0.1	0.1
4	0.1	6	0.0025	100	180	0.25	0.45
		7	0.2	0	5	0	1
5	0.02	1	0.4	0	7	0	2.8
		2	0.4	10	0	4	0
		3	0.5	0	7	0	3.5
		4	0.5	5	0	2.5	0
6	0.07	8	0.01	3	14	0.03	0.14
		9	0.01	100	110	1	1.1
		10	0.01	20	10	0.2	0.1
		13	0.2	0	4	0	0.8
7	0.05	5	0.05	100	90	5	4.5
		7	0.05	5	3	0.25	0.15
		11	0.15	0	14	0	2.1
		12	0.15	10	0	1.5	0
		17	0.01	0	2	0	0.02
		18	0.01	2	0	0.02	0
8	0.02	1	0.4	0	20	0	8
		2	0.4	40	0	16	0
		3	0.5	0	14	0	7
		4	0.5	30	0	15	0
9	M	14	0.3	1	0	0.3	0
		15	0.2	0	2	0	0.4
		16	0.2	2	0	0.4	0
		17	0.01	0	2	0	0.02
		18	0.01	2	0	0.02	0
		19	0.01	2	1	0.02	0.01
		20	0.3	3	5	0.9	1.5
		21	0.1	20	0	2	0
		22	0.1	0	30	0	3
10	0.03	17	0.1	0	2	0	0.2
		18	0.1	2	0	0.2	0
		13	0.1	0	2	0	0.2
11	0.02	14	0.1	4	2	0.4	0.2
12	0.04	19	0.1	7	5	0.7	0.5
13	0.05	17	0.01	0	1	0	0.01
		18	0.01	1	0	0.01	0
14	M					0	0
15	M	20	0.2	5	10	1	2
		23	0.05	100	90	5	4.5
16	M					0	0
17	M	17	0.01	0	1	0	0.01
		18	0.01	1	0	0.01	0
		24	0.02	1	1	0.02	0.02
18	M	13	0.3	3	3	0.9	0.9
19	0.06	17	0.01	0	1	0	0.01
		18	0.01	4	0	0.04	0

It should be noted that the use of a single particular strategy for each risk affects the reliability of the problem. Therefore, PMs developed the strategies listed in Table 3 to deal with each risk properly.

Table 3: Cost and time benefits of RRS to primary risks

Activity no.	Risk no.	RRS no.	RRS	Cost benefit of RRS to primary risk	Time benefit of RRS to primary risk	Cost of implementing the RRS
i	l	k		$ecosts_{ilk}$	$etime_{ilk}$	$cactions_{ilk}$
1	1	1	Selecting bidders out of qualified vendor lists	0.05	2	0.05
		2	Pre-evaluation of bidders	0.02	0.5	0.2
		3	Considering technical appraisal scores when determining the winner	1	0.5	1
	2	1	Selecting bidders out of qualified vendor lists	8	0	0.05
		2	Pre-evaluation of bidders	2	0	0.2
		3	Considering technical appraisal scores when determining the winner	1	0	1
	3	4	Employing experienced personnel	0.5	2	0.5
		5	Preparing clear and flawless tender documents	0.3	3	0.3
		6	Holding Q&A sessions	0.3	1	0.3
	4	4	Employing experienced personnel	2	0	0.5
		5	Preparing clear and flawless tender documents	5	0	0.3
		6	Holding Q&A sessions	1	0	0.3
2	5	7	Buying insurance coverage for equipment transport	4	0	1
		8	Suitable leaching	0.5	3	0.3
		9	Using professional fleet for escort	0.5	1	0.2
5	1	1	Selecting bidders out of qualified vendor lists	0.05	1.5	0.05
		2	Pre-evaluation of bidders	0.2	0.4	0.2
		3	Considering technical appraisal scores when determining the winner	1	0.5	1
	2	1	Selecting bidders out of qualified vendor lists	2.5	0	0.05
		2	Pre-evaluation of bidders	0.6	0	0.2
		3	Considering technical appraisal scores when determining the winner	0.3	0	0.5
	3	4	Employing experienced personnel	0.5	1	0.5
		5	Preparing clear and flawless tender documents	0.3	1.5	0.3
		6	Holding Q&A sessions	0.3	0.5	0.3
7	5	7	Buying insurance coverage for equipment transport	4	0	1
		8	Suitable leaching	0.5	3	0.3
		9	Using professional fleet for escort	0.5	1	0.2
8	1	1	Selecting bidders out of qualified vendor lists	0.05	4	0.05
		2	Pre-evaluation of bidders	0.2	2	0.2
		3	Considering technical appraisal scores when determining the winner	1	1	1
	2	1	Selecting bidders out of qualified vendor lists	12	0	0.05
		2	Pre-evaluation of bidders	3	0	0.2
		3	Considering technical appraisal scores when determining the winner	1	0	1
	3	4	Employing experienced personnel	0.5	2	0.5
		5	Preparing clear and flawless tender documents	0.3	3	0.3
		6	Holding Q&A sessions	0.3	1	0.3
	4	4	Employing experienced personnel	4	0	0.5
		5	Preparing clear and flawless tender documents	10	0	0.3
		6	Holding Q&A sessions	2	0	0.3
9	22	10	Purchasing or leasing the required technology	0.3	2	0.3
15	23	11	Buying insurance coverage for whole installation risk	3	0	0.6
		12	Holding sensitive operation maneuvers	0.5	3	0.1

With the time and cost benefits of implementing the primary risks explained in Table 3, let us proceed to secondary risks and their time and cost impacts. This is depicted in Table 4.

Table 4: Cost and time benefits of RRS to secondary risks

Activity no.	Risk no.	RRS no.	RRS	Cost impact	Time impact	Cost of implementing the RRS	Cost benefit	Time benefit
i	l	k		$qcosts_{ilk}$	$qtimes_{ilk}$	$cactions_{ilk}$	$ecosts_{ilk}$	$etimes_{ilk}$
1	2	1	SR1	5	2	0.5	4	1.5
1	4	4	SR2	2	1.5	0.5	2	5
8	2	1	SR3	4.5	2	0.01	4	1.5
8	4	4	SR4	5	0.4	SR4	5	0.4
9	22	10	SR5	2	0.2	0.05	5	0.1
1	2	1	SR1	5	2	0.5	4	1.5

As explained in the section on modeling, we further need to determine per-activity maximum risk budget, minimum time required to accomplish, and maximum allowable delay, as detailed in Table 5.

Table 5: Values of time and budget constraints for different activities

Q(I)	DMIN(I)	DSTAR(I)
4	10	2.5

Using the above-presented data, one can do the required planning objectively. Solving the research problem using the CPLEX solver, the following numerical results were obtained.

Table 6: Anticipated improvements in primary and secondary risks

Total anticipated primary risk	Optimal cost of primary risk	Improvement obtained upon responding to primary risk	Total anticipated secondary risk	Optimal cost of secondary risk	Improvement obtained upon responding to secondary risk
84.540	29.090	55.45	8.50	3.060	5.44

From the results, it is clear responding to the primary and secondary risks can mitigate some 64% of the risk, which is a very good outcome for the model and makes it worth considering at a managerial level. With the improvements achievable by the model been well known, we now proceed to evaluate total system cost, as reported in Table 7.

Table 7: Total cost of project

Primary risk cost	Secondary risk cost	Crash cost	Total cost
29.090	3.060	0.630	32.780

As the table implies, primary and secondary risks could be addressed by spending 29.090 and 3.060 cost units, respectively. Finally, the crashing cost of activities was evaluated at 0.630 cost units. Table 8 presents the strategies assigned to different primary risks associated with different activities.

Table 8: Assignment of RRSs to primary risks

Activity	Risks	Strategy											
		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
I1	R1	1		1									
I1	R2	1	1	1									
I1	R3				1	1	1						
I1	R4				1	1	1						1
I2	R5							1	1	1			
I7	R5							1	1				
I8	R1	1	1	1									
I8	R2	1	1	1									
I8	R4					1	1						
I9	R22										1		
I15	R23											1	1

In Table 8, the 1s the assignment of the relevant strategy to deal with the risk imposed on the corresponding activity.

Similarly, strategies assigned to secondary risks are explained in Table 9.

Table 9: Assignment of RRSs to secondary risks

Activity	Risks	Strategy											
		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
I1	R4				1								
I8	R2	1											
I9	R22										1		

Table 9 depicts that the RRSs whose cost of implementation was high compared to the relevant risks were eliminated by the model, indicating the high efficiency of the model.

SENSITIVITY ANALYSIS

In this section, a sensitivity analysis was performed on the problem variables. This was begun by analyzing the sensitivity of the RRS to primary risks on the change in the cost of implementing the RRSs. To this end, a change was made to the costs of implementing RRSs (Table 10).

Table 10: Cost and benefit of implementing RRS to primary risks before and after the change

After model change						Before change					
$ecost_{ilk}$			$caction_{ilk}$			$ecost_{ilk}$			$caction_{ilk}$		
k	l	i	k	l	i	k	l	i	k	l	i
9	5	2	8	5	2	9	5	2	8	5	2
6			1			2			0.3		
3	1	8	2	1	8	3	1	8	2	1	8
3			1			0.7			0.2		
12	23	15	11	23	15	12	23	15	11	23	15
4			0.5			3.5			0.6		

Tables 11 and 12 present the effects of changing the cost of RRSs on the assignment of RRSs to primary risks.

Table 11: RRS to primary risks before changing the cost and benefit of the RRSs

Activity	Risks	Strategy											
		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
I1	R1	1	-	1									
I1	R2	1	1	1									
I1	R3				1	1	1						
I1	R4				1	1	1						1
I2	R5							1	1	1			
I7	R5							1	1				
I8	R1	1	1	1									
I8	R2	1	1	1									
I8	R4					1	1						
I9	R22										1		
I15	R23											1	

Table 12: RRS to primary risks after changing the cost and benefit of the RRSs

activity	risks	strategy											
		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
I1	R1	1	-	1									
I1	R2	1	1	1									
I1	R3				1	1	1						
I1	R4				1	1	1						1
I2	R5							1	0	1			
I7	R5							1	1				
I8	R1	1	0	1									
I8	R2	1	1	1									
I8	R4					1	1						
I9	R22										1		
I15	R23											0	1

As can be seen from Table 12, the increase in the cost of RSS led to a change in the choice of optimal set of RSSs, indicating proper functioning of the proposed model.

Results of Metaheuristic Algorithm

Based on the results presented in the previous sections, the proposed model was found to be able to provide acceptable numerical results, as was further confirmed by the results of the sensitivity analysis. In this section, more extensive numerical analyses were conducted on the results. This was done by means of GA – a population-based algorithm with well-known applicability to a wide spectrum of problems. In order to compare the results, 10 numerical examples were randomly generated and the results of the metaheuristic algorithm were evaluated against those of the GAMS software.

Table 13: Results of the metaheuristic algorithms

Example	**Dimension**			**GAMS Software**	**GA**	
	i	**l**	**k**	**Total cost**	**Total cost**	**Processing time**
Case study	19	24	12	32.780	32.780	14.8
2	40	48	20	250365	250,365	11.7
3	60	80	30	-	456,365	13.0
4	80	120	40	-	655.365	12.9
5	100	160	50	-	896.329	12.0
6	120	190	60	-	1234,456	11.9
7	140	200	70	-	2451.325	13.9
8	160	230	80	-	2675.315	11.6
9	180	250	90	-	3535.236	14.3
10	200	300	100	-	4562.320	14.9

Table 13 indicates that the GAMS software can no more solve the problem as the size of problem grows. In other words, the growth of the processing time is proportional to the problem size, indicating solvability of problems with even larger sizes.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

In this research, firstly, 24 probable risks on the activities planned for transporting and installing an 800-ton tower were identified based on the information collected from experts. Next, a model was developed to formulate strategies for responding to primary risks. Based on the results, it was found that implementation of the proposed model reduced the cost of responding to the primary risks from 84.540 down to 29.090 cost units. Upon responding to the primary risks, the project was exposed to secondary risks that required 8.500 cost units to respond. However, risk response strategy (RRS) selection using the proposed model reduced the latter cost down to 3.060 cost units. The optimal crashing price of activities was evaluated at 0.630 cost units. According to the results of sensitivity analysis, it was figured out that the maximum allowable delay for project completion was 78 days, beyond which the crashing cost of activities would become zero. In this work, genetic algorithm (GA) – a metaheuristic algorithm – was adopted to solve the problem at large scale, with the results indicating good efficiency of the GA when it came to the processing time.
Several recommendations for future studies are presented in the following:

- In order to consider the problem more comprehensively and avoid conservative responses from the participating experts, future researchers are recommended to use a combination of interviews and questionnaires in all stages of their work. Indeed, the face-to-face two-way communication in an interview sets the scene for getting access to richer information. It is worth noting that, in this work, such interviews were performed only for formulating RRSs.
- Interested researchers are recommended to investigate the use of MCDM techniques such as PROMETHEE, ELECTRE, etc. for ranking and more accurate sensitivity analysis.
- Interested researchers are recommended to investigate the problem in other private and public companies where risk management is a concern.

REFERENCES

1. Adeleke, A. Q., Bahaudin, A. Y., Kamaruddeen, A. M., Bamgbade, J. A., Salimon, M. G., Khan, M. W. A., & Sorooshian, S. (2018). The influence of organizational external factors on construction risk management among Nigerian construction companies. *Safety and Health at Work,* 9(1), 115-124.
2. Chu, Y., & Wang, Z. (2020). *Research on project risk response strategy selection based on grey K-shell algorithm.* Grey Systems: Theory and Application.
3. Fattahi, R., & Khalilzadeh, M. (2018). Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. *Safety science,* 102, 290-300.
4. Denisova, A. I. (2021, March). *Assessment of Options for Substantiating an Infrastructure Project Implementation Plan in the Presence of Associated Risks.* In IOP Conference Series: Earth and Environmental Science (Vol. 666, No. 6, p. 062075). IOP Publishing.

5. Huang, X., & Zhao, T. (2014). Project selection and scheduling with uncertain net income and investment cost. *Applied Mathematics and Computation,* 247, 61-71.
6. Khalili-Damghania, Kaveh, Nojavana, M., & Tavanab, M. (2013). Solving fuzzy Multidimensional Multiple-Choice Knapsack Problems: The multi-start Partial Bound Enumeration method versus the efficient epsilon-constraint method. *Applied Soft Computing,* 13, 1627–1638.
7. Koulinas, G. K., Marhavilas, P. K., Demesouka, O. E., Vavatsikos, A. P., & Koulouriotis, D. E. (2019). Risk analysis and assessment in the worksites using the fuzzy-analytical hierarchy process and a quantitative technique–A case study for the Greek construction sector. *Safety Science,* 112, 96-104.
8. Kuo, R. J., Nugroho, Y., & Zulvia, F. E. (2019). Application of particle swarm optimization algorithm for adjusting project contingencies and response strategies under budgetary constraints. *Computers & Industrial Engineering,* 135, 254-264.
9. Khodeir, L. M., & Mohamed, A. H. M. (2015). Identifying the latest risk probabilities affecting construction projects in Egypt according to political and economic variables. *From January 2011 to January 2013. HBRC Journal,* 11(1), 129-135.
10. Khalilzadeh, M., Ghasemi, P., Afrasiabi, A., & Shakeri, H. (2021). Hybrid fuzzy MCDM and FMEA integrating with linear programming approach for the health and safety executive risks: a case study. *Journal of Modelling in Management.*
11. Liu, H. C., Liu, L., & Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: A literature review. *Expert systems with applications,* 40(2), 828-838.
12. Mousavi, S. M. (2012). A multi-criteria decision-making approach with interval numbers for evaluating project risk responses. *International Journal of Engineering,* 25(2), 121-130.
13. Rafindadi, A. D. U., Mikic, M., Kovacic, I., & Cekic, Z. (2014). Global perception of sustainable construction project risks. *Procedia-Social and Behavioral Sciences,* 119, 456-465.
14. Piedade, L., & Silva, J. Optimized communication plan and its impact on the contingency plan previously put in place for timely crisis response in the air sector. *VII RIDITA-Air Transportation Sustainability: Technological, Operational, Economic, Social and Environmental Strategies, 1(VII RIDITA),* 465-473.
15. Sols, A. (2018). A comprehensive approach to dynamic project risk management. *Engineering Management Journal,* 30(2), 128-140.
16. Taylan, O., Bafail, A. O., Abdulaal, R. M., & Kabli, M. R. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing,* 17, 105-116.
17. Zuo, F., & Zhang, K. (2018). Selection of risk response actions with consideration of secondary risks. *International Journal of Project Management,* 36(2), 241-254.
18. Zhang, Y. (2016). Selecting risk response strategies considering project risk interdependence. *International Journal of Project Management,* 34(5), 819-830.
19. Zhang, H., & Sun, Q. (2020). An Integrated MCDM Approach to Train Derailment Risk Response Strategy Selection. *Symmetry,* 12(1), 47.
20. Zhang, Y., Zuo, F., & Guan, X. (2020). Integrating case-based analysis and fuzzy optimization for selecting project risk response actions. *Physica A: Statistical Mechanics and its Applications,* 545, 123578.
21. Wang, L., Sun, T., Qian, C., Goh, M., & Mishra, V. K. (2020). Applying social network analysis to genetic algorithm in optimizing project risk response decisions. *Information Sciences,* 512, 1024-1042.
22. Yang, T., Zhang, Q., Wan, X., Li, X., Wang, Y., & Wang, W. (2020). Comprehensive ecological risk assessment for semi-arid basin based on conceptual model of risk response and improved TOPSIS model-a case study of Wei River Basin, China. *Science of The Total Environment,* 137502.
23. Kalantari, S. S., & Taleizadeh, A. A. (2020). Mathematical modelling for determining the replenishment policy for deteriorating items in an EPQ model with multiple shipments. *International Journal of Systems Science: Operations & Logistics,* 7(2), 164-171.
24. Masoumnezhad, M., Rajabi, M., Chapnevis, A., Dorofeev, A., Shateyi, S., Kargar, N.S. and Nik, H.S., 2020. An Approach for the Global Stability of Mathematical Model of an Infectious Disease. *Symmetry,* 12(11), p.1778.https://www.mdpi.com/2073-8994/12/11/1778.
25. Arasteh, S., Mahdavi, M., Bideh, P.N., Hosseini, S. and Chapnevis, A., 2018, May. Security Analysis of two Key Based Watermarking Schemes Based on QR Decomposition. *In Electrical Engineering (ICEE), Iranian Conference on* (pp. 1499-1504). IEEE.https://ieeexplore.ieee.org/abstract/document/8472576.
26. Chapnevis, A. and Sadeghiyan, B., 2020. A Secure Two-Party Computation Protocol for Intersection Detection between Two Convex Hulls. arXiv preprint arXiv:2011.00319.https://arxiv.org/abs/2011.00319.