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A mathematical modeling of project risk response according to primary, secondary, and residual risks under conditions of uncertainty using the Tabu search algorithm

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Abstract

Today, the uncertainty in the estimated time and cost of industrial projects is considered as an important challenge in the science of project management. If risk management is done regularly to identify potential problems and find their solution, it will easily complement other processes such as organizing, planning, budgeting, and cost control. In this regard, one of the most important and effective solutions to this problem is risk analysis (primary, secondary, and residual). In this research, an optimization model has been proposed to select actions to respond to risk for all three primary, secondary and residual risks. This research is quantitative. In building the model, the objective function is to minimize the total risk costs and the costs of reducing the time constraints applied to the relationship between two activities. Then, by determining a suitable reasonable time for the whole project and solving the model, an optimal set of actions to respond to the risks is determined. The basic innovation of this research, which does not cause the selection of a predetermined strategy, is the two limitations that examine the two dimensions of time and cost in response to primary and secondary risk. The results indicate that the initial risk costs have decreased. Also, by responding to the primary risk, secondary risks were created, which imposed a cost on the system, but this cost was reduced by assigning secondary strategies, as well as the optimal cost of activity failure with the sensitivity analysis that was done, the maximum amount of time that the project can end It was equal to 78 days and more than that makes the cost of failure of activities to be zero. Also, in this research, the genetic meta-heuristic algorithm and the Particle swarm algorithm were used to solve the problem in high dimensions, and the results showed that there is no difference in the results of these two algorithms.

Keywords: Risk response strategy, Tabu search algorithm, particle swarm algorithm, genetic algorithm

1-Introduction

Risk management is a process that aims to reduce the harmful consequences or increase the positive effects of a possible event through conscious action to predict events and plan to interact with them. In general, risk management can be considered the process of measuring or evaluating risk and then planning strategies for risk management.

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In general, the strategies used include transferring risk to other sectors, avoiding risk, reducing the negative effects or increasing the positive effects of risk, accepting part or all of the consequences of risk, or promoting decision-making regarding specific risks to higher levels of the organization. In addition to identifying risks and determining their quality, risk management systems can also predict their effects on the project. Accepting or not accepting risk usually depends on the level of resilience of the project manager and the organization. If risk management is done regularly to identify potential problems and find their solution, it will easily complete other processes such as organization, planning, budgeting, and cost control. A project manager who is a pioneer in this field can largely prevent the occurrence of unexpected events during the life of the project (Zuo and Zhang, 2018; Abolghasemian et al., 2021).

Risk management throughout the life cycle of the project, from the beginning of the initial phase to the end of the closing phase, is continuous and proactive, among the basic requirements for the success of any project-oriented organization (Bayanati et al. 2022). To identify and effectively manage risks in all phases of the project, a conscious choice must be made at all levels of the organization. Risk can exist from the moment the project starts. Moving the project forward without an active focus on risk management can lead to very serious problems, problems that arise from unmanaged risks (Feng et al., 2021; Touti and Chobar, 2020). Risk is considered an uncertain event that affects at least one of the project's objectives if it occurs. This effect can be positive or negative. During project planning, project managers have little information about the risks associated with each activity, and as a result, time delays, additional costs, and reductions in quality lie in waiting for them (Asgari et al. 2022). According to Wang (2019), if the risk is not answered correctly, the impact of risk identification and assessment will be reduced. However, in practice, the issue of responding to risk is not given enough attention compared to its identification. In the stage of response to threats, five strategies are used, which are avoidance, transfer, reduction, acceptance, and improvement of the decision-making level. These five strategies with different goals are chosen by project managers according to different conditions or projects according to the severity of risks, access to resources, and other factors related to project goals. Specifically, risk avoidance refers to the elimination of threats caused by risks, while risk reduction aims to reduce the probability of occurrence or its impact to an acceptable level. To prevent the occurrence of the risk, risk avoidance is always done by removing all activities related to that risk from the main plan. Risk avoidance, although effective, may lead to a certain complexity in project management, as new risks are created by new activities. In contrast, risk mitigation, which appears to be more practical, reduces activity risk by selecting and implementing a new set of actions in response. Therefore, choosing the appropriate response to risks reduces hidden threats in project activities.

Any response that is defined for project risks will lead to a change in the risk status of the project. It is clear that the response is designed to improve the project's risk situation, but there can be no assurance that the response will necessarily work as planned or that the result of the response planning will only affect the intended risk. In some cases, the implementation of the response may eliminate the intended risk, but in turn, because other risks for the project. The risks resulting from the implementation of the response are called secondary risks. It is necessary to identify the secondary risks resulting from the response to the main risks of the project and evaluate them in the same order as the main risks. For this purpose, it should be determined what the risk status of the project will be after the implementation of the answers. In addition to secondary risk, residual risk will be considered in this research, which is a level of risk that still exists despite creating control factors and trying to reduce risk. In other words, after the types of primary and secondary risks have been identified and managed, there is still a level of risk that we are unable to control and identify initially. Residual risks are those that remain after avoidance, transfer, or mitigation responses have been adopted. These risks also include minor risks that have been investigated and accepted. In general, part of project implementation costs is related to residual risks (Zhang et al., 2016; Chobar et al., 2022). In this research, the secondary and residual risk is not viewed only from the perspective of threat because secondary risk can be an opportunity. In other words, the unintended consequences of a response can be positive or negative. The status of secondary risks regarding threats is almost clear. The goal of responding to these risks is to deal with the original risk without creating a new threat, or at least to ensure that the risk status of the project after implementing the response is no worse than it was before the response was implemented. As for opportunities, the analysis of secondary risks is more complex. Considering secondary threats and opportunities can lead to changes in decision-making to implement responses and choose the best decisions.

The remainder of this paper is organized as follows: The next section reviews related work, highlighting the research gaps and the contributions of this paper. Section 3 describes the research methodology, the types of response policies considered, the mathematical formulation, and how the model was verified and validated. Section 4 describes the numerical results used to optimize response strategies. Section 5 sensitivity analysis presents the obtained by implementing the proposed framework in a real case study. Finally, conclusions and possible extensions are provided in section 6.

2- Literature review

Tantri et al. (2022), used the principles of social resilience in modeling and simulating responses to disasters in urban areas. It focuses on the role of hospitals as part of the healthcare infrastructure in response to a large-scale disaster. Each hospital is modeled as a coordinated location with a certain amount of resources, primarily medical staff. They performed sensitivity analysis through Monte Carlo simulations to observe the effects of different response strategies, disaster severity, and communication duration on system resilience. Liu et al. (2022), in their research, defined an evacuation planning problem for stranded passengers along a broken line, which was considered a series and growing with time. They proposed a combined NSGA-II algorithm and ant colony optimization to solve the model. A case study applies three transportation-based response strategies to high-speed rail disruption in the Beijing-Hebei urban corridor. The results showed that the proposed strategy provides a lower risk level with acceptable cost and discharge balance points than other strategies and differentiates transit passengers into groups, which results in lower delay and residual amount. The results showed that centralized systems are generally better suited to deal with low-intensity disasters, while a decentralized strategy performs better during a disaster with worse effects. Gillis et al. (2021) proposed a simulation optimization to help policymakers choose the package of protection and travel policies to minimize the number of sets with a limited budget. Their proposed paper examines a modified and classified SEIR segmentation model for assessing the health of response strategies and a genetic algorithm for search. They believed that epidemics require dynamic response strategies that include many alternative policies and health, economic, and social considerations. The results showed that social distancing and the use of masks are necessary for situations where the economic cost is bearable. Ghasemi et al. (2022), believed that there are a large number of interrelated risk factors in complex projects. A risk response strategy cannot achieve a good risk response without considering risk correlation. Therefore, his goal is to present a risk response strategy selection model based on the K-shell gray algorithm based on the risk correlation. He stated that the risk response strategy is more effective than the risk response strategy regardless of the risk correlation. Is. Also, the results indicate that as the risk response budget increases, the risk response effect also increases, and the growing trend is weakened. The relative distance between the effect of response strategies considering the risk and the strategy without considering the relevance of risk initially increases and then decreases as the budget increases. Lei Wang et al. (2020) investigated the risk response strategy for risk interactions and used a simulation model to evaluate decisions and used a genetic algorithm to solve the optimization problem. Zhang et al. (2020) used the combined DEMATEL method and network analysis to weigh the risks caused by leaving the train at the railway station and identified risk response strategies using the Delphi method and then using the TOPSIS method to rating of risk response strategies. Lei Wang et al. (2019) used a simulation model to investigate the risk response strategy with regard to the interaction of risk and payment and used a genetic algorithm to solve the optimization problem.

3- Research methodology

In general, quantitative research is a practical procedure for testing theories. This research often pointed to large numerical samples that can be formulated as mathematical and random models (Ketokivi & Choi, 2014; Pourghader chobar et al., 2022). These researches examine theoretical concepts in terms of amount, intensity, and frequency. The nature of quantitative research is based on the principle of formulating a complex problem in the form of numerical variables and then analyzing the behavior of the model by analyzing these variables separately. The most important features of decision variables in quantitative research include incrementality, experimentality, generalizability, summarization, repeatability, refutability, systematicity, objectivity, and specialization. The problem presented in this research is also presented in the form of mathematical formulation based on the conditions in the real world and finally, through the analysis of numerical variables, implementable answers are provided to the users of the research. Therefore, this research belongs to the category of quantitative research.

One of the most important steps in the process of conducting quantitative research is the proper collection of data as input parameters. Since the data required for this research is often in the form of quantitative data, therefore, data collection methods include articles related to the research field, websites affiliated with international reference institutions (such as the World Health Organization for Checking the statistics related to the spread of the Coronavirus) and the national statistics centers in the countries under study. It is also possible to use the data collected in the field as input data for the research. If there are qualitative parameters, the use of questionnaires and interviews is the best data collection tool.

3-1-Mathematical modeling of research

To respond to primary and secondary risks, the following mathematical modeling was used.

Indexes:

i Prerequisite activity number
j Activity after need
l Risk
k Response strategy

Parameters:

$qcost_{il}\ f$	The expected cost of initial risk *l* on activity *i*
$qtime_{il}$	The expected amount of time for initial risk *l* on activity *i*
$ecost_{ilk}$	The amount of cost savings resulting from allocating strategy *k* on the initial risk *l* in activity *i*
$etime_{ilk}$	The amount of time savings resulting from allocating strategy *k* on the initial risk *l* in activity *i*
$caction_{ilk}$	The amount of cost resulting from allocating strategy *k* on the initial risk *l* in activity *i*
$qcosts_{ilk}$	The amount of unanticipated cost resulting from secondary risk *l* on activity *i* resulting from allocation of secondary strategy *k*
$ecosts_{ilk}$	The amount of unanticipated profit resulting from the secondary risk *l* on the activity *i* resulting from the allocation of strategy *k*
$qtimes_{ilk}$	Unanticipated time cost effect caused by secondary risk
$etimes_{ilk}$	The amount of benefit is the unanticipated time effect of the secondary outcome
$cactions_{ilk}$	The amount of cost resulting from allocating strategy *k* on secondary risk *l* in activity *i*

$ccrash_i$	Activity failure*(i)*
q_i^*	The maximum amount of risk budget for each activity
d_i^*	Acceptable machine for any activity
$dmin_i$	The minimum time required to perform the activity

After introducing the variables and parameters of the model, it is necessary to examine the objective functions and limitations, which is as follows:

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

As it is clear from the above equation, the predicted cost of risk occurrence on each activity is added to the cost of responding to the risk, and it is subtracted from the amount of cost savings resulting from responding to the risk. This equation is the optimization of the initial risk cost of the project. will pay. But the important point is the amount of the remaining risk cost, which is included in the above equation in the form of the following equation:

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

The next equation that must be explained is the equation related to secondary risk is the result of the strategy's response to primary risks, some of which may cause secondary risk, for this reason, the second objective function is to minimize the cost of responding to It is a secondary risk whose equation is as follows:

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

As it is clear from the above equation, the unanticipated cost of the occurrence of secondary risk on each activity is added with the cost of responding to the secondary risk and it is subtracted from the amount of cost saving resulting from the response to the risk. In fact, this equation is the optimization of risk cost. The secondary of the project will pay. But the important point is the amount of the remaining risk cost, which is included in the above equation in the form of the following equation:

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

The cost of failure of the activities is as follows:

$$minz_3 = \sum_i ccrash_i * x_i \quad (5)$$

After the cost of activity failure was determined, all the goals of the model were described, and the main goal is to minimize the cost of primary and secondary risk and the cost of activity failure, the limitations of the model should be described, and the first limitation that should be described is the limitation that causes the formation of The node network of the problem will be as follows:

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

The above limit will calculate the completion time of the activities. The next limit that must be described is the limit that determines the maximum amount of time an activity can be delayed, which is through the following equation:

$$drisk_i = \sum_l qtime_{il} - \sum_l \sum_k etime_{ilk} * y_{ilk} + \sum_i \sum_l \sum_k qtimes_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k etimes_{ilk} * y'_{ilk} \qquad \forall(l,k) \tag{6}$$

The upper limit calculates the remaining time due to the occurrence of project risk, which is caused by primary and secondary risks.

The completion of the above limits will happen with the following three conditions:

$drisk_i \geq 0 \qquad \forall(i)$

$x_i \geq 0 \qquad \forall(i)$

$x_i \leq d_i - dmin_i \qquad \forall(i)$

In fact, the above conditions state that the failure time of activities is at least greater than zero and at most equal to the normal time difference with the smallest activity delay. We will pay the limits related to the risk costs as follows:

$$\sum_l qcost_{il} - \sum_l \sum_k ecost_{ilk} * y_{ilk} + \sum_i \sum_l \sum_k qcosts_{ilk} * y_{ilk} - \sum_i \sum_l \sum_k ecosts_{ilk} * y'_{ilk} \leq q_i^* \qquad \forall(l,k) \tag{7}$$

In fact, the upper limit is a limit that will check the allocated amount of the budget so that the total cost of the remaining primary and secondary risk does not exceed the amount of the budget. which does not cause the selection of a predetermined strategy. These are the following two limitations that examine the two dimensions of time and cost in response to primary and secondary risk, which are as follows:

$$ecost_{ilk} + etime_{ilk} * ccrash_i \geq caction_{ilk} * y_{ilk} \qquad \forall(i,l,k) \tag{8}$$

$$ecosts_{ilk} + etimes_{ilk} * ccrash_i \geq cactions_{ilk} * y'_{ilk} \qquad \forall(i,l,k) \tag{9}$$

These two restrictions will work in such a way that if the benefits of responding to the primary and secondary strategies are greater than the cost of responding to the activity, then that strategy will be chosen, and if that response does not create a benefit, that strategy will not be chosen.

Now, after this limitation, we have to deal with the relationship between the primary and secondary strategy allocation variable, which is as follows:

$$y_{ilk} \geq \boldsymbol{y'_{ilk}} \qquad \forall(i,l,k) \tag{10}$$

The upper limit shows the dependence of the secondary risk on the primary one, which means that the secondary risk will not be assessed until the primary risk is assessed.

4-Numerical results

In this section, the numerical results of solving the mathematical model in a specific numerical example are explained. For this purpose, first of all, it is necessary to state the conditions of the numerical example to get a proper idea of the environmental conditions of the problem.

Zargan power plant is one of Iran's thermal power plants, which includes 4 gas units of 32 MW and 2 steam units of 145 MW in a land of 45 hectares. The basic repairs of unit 2 of the Zargan power plant in 2018 were entrusted to Azarab Arak Industries due to the capabilities and expertise of the experts and by abandoning the tender procedures. As a result, for the first time, repairs on this extensive level have been ready for operation in less than a year. According to the contract of the said project, it is defined for 4 months, but the operation of Retube Boiler started in December 2018 and ended in the middle of June 1400, and during this period, the project was repeatedly postponed by the contractor for reasons such as the spread of the Coronavirus, power outages, end-of-year holidays, etc. During the days of Ramadan, failure to equip the workshop on time by the contractor company, cost discussion with the client company, non-approval of connections and bending works by the client's supervisors, and the lack of Arab Arak company, the project was partially shut down, which caused a lot of damage to this power plant.

The implementation of each activity has its priority and delay, which can be drawn in the form of a nodal network. This network is based on the requirements of each activity to implement previous and subsequent activities. Therefore, the following figure can be drawn.

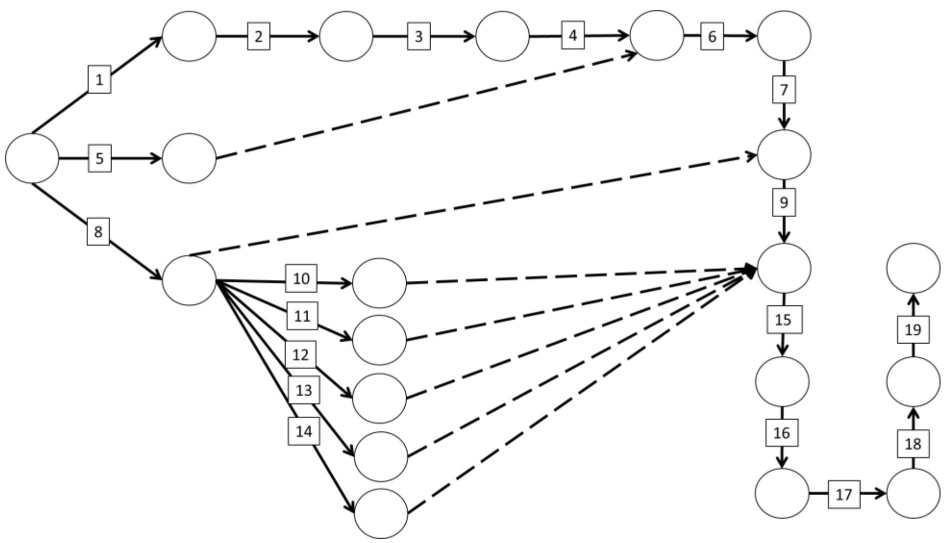

Fig 1. Network of activities

This activity network has specific information regarding the duration of time required to execute each activity, as well as data related to the earliest/latest start/end time. Another important point in solving the research problem is that there are a set of risks in the project implementation process that must be planned to deal with them. In this research, 24 different risks have been considered.

It is not possible to use a specific strategy for every existing risk because ultimately the reliability of solving the problem will be affected. Therefore, according to the opinion of the project managers, strategies are considered to deal with each of the existing risks. It should be noted that the measures related to the response to the primary risk will cause the emergence of secondary risk, which is itself effective in terms of time and cost, and the cost and time effectiveness values and the response strategy to the secondary risk will be. After the amount of time and money cost of responding to the secondary risk is determined, it is necessary to determine the amount of benefit from these strategies.

As described in the research modeling, we must specify the parameter values (maximum amount of risk budget for each activity, minimum time required to perform the activity, and maximum acceptable delay required for each activity).

Then the necessary planning can be done to solve the problem in a targeted manner. After solving the research problem using the Cplex solver using the available data, the following numerical results are obtained.

Table 1. The amount of improvement in primary and secondary risk values

The amount of improvement after applying secondary risk response	The optimal amount of initial risk cost	The sum of the predicted secondary risk caused by the reaction to the primary risk	The amount of improvement after applying the reaction to the initial risk	The optimal amount of initial risk cost	The sum of the predicted initial risk
5.44	3.060	8.50	55.45	29.090	84.540

As it is clear from the results above, the reaction to primary and secondary risk has caused an approximate 64% reduction in risk, which is a very good result for the model and these results can be examined at the management level. The total cost of the system is determined as described in the following table:

Table 2. All project costs

total cost	**cost of failure**	**Cost of secondary risk**	**Initial risk cost**
32.780	0.630	3.060	29.090

As can be seen, the cost of primary risk is equal to 29.090 and the cost of secondary risk is equal to 3.060 monetary units. Finally, the cost of activity failure is equal to 0.630 currency units. The following figure compares graphically the cost of different departments.

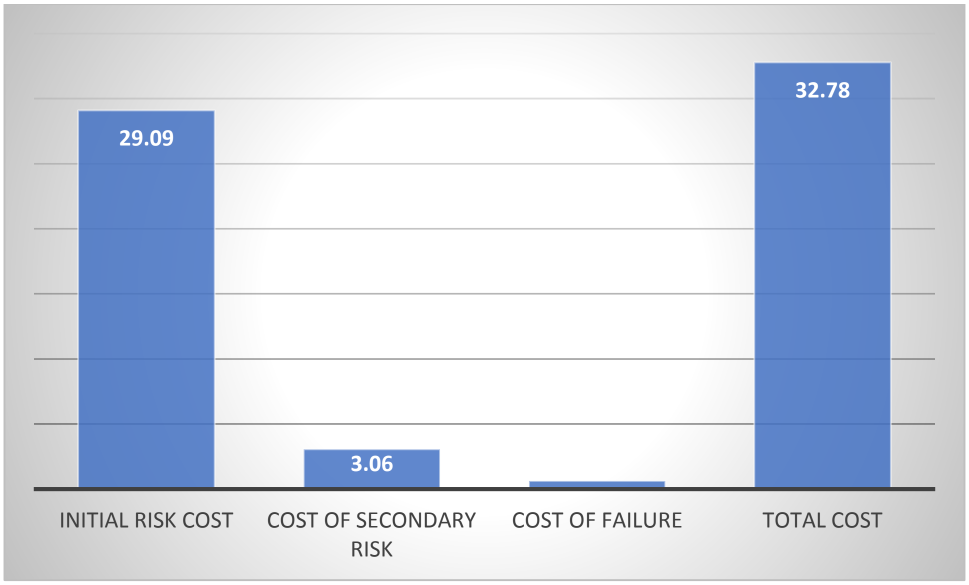

Fig 2. Comparison of the costs of different departments

In total, about 88% of the total cost is related to primary risk, 9% is related to secondary risk, and the rest is related to the cost of failure of activities. The first variable is the optimal rate of activity failure, which is as follows:

Table 3. The optimal failure rate of each activity

Activity number				
1	2	4	6	**7**
failure rate				
4	1	3	1	**2**

Now, after the optimal rate of failure of each activity is determined, it is necessary to determine the optimal rate when the activity is under risk, which is according to the following table:

Table 4. Delay time of activities in optimal mode

Activity	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11
Delay time	1	0.77	1.020	1.450	0.800	2.140	1.770	2.500	2.030	0.400	0.200
Risk	I12	I13	I14	I15	I16	I17	I18	I19			
Delay time	0.500	0.010	0	1.500	0	0.030	0.900	0.010			

As can be seen, activity 8 with a delay of 2,500 days has more value. Also, the activities of the 14th and 16th will start with a delay of 0 days. The figure below shows a complete comparison of optimal delay times.

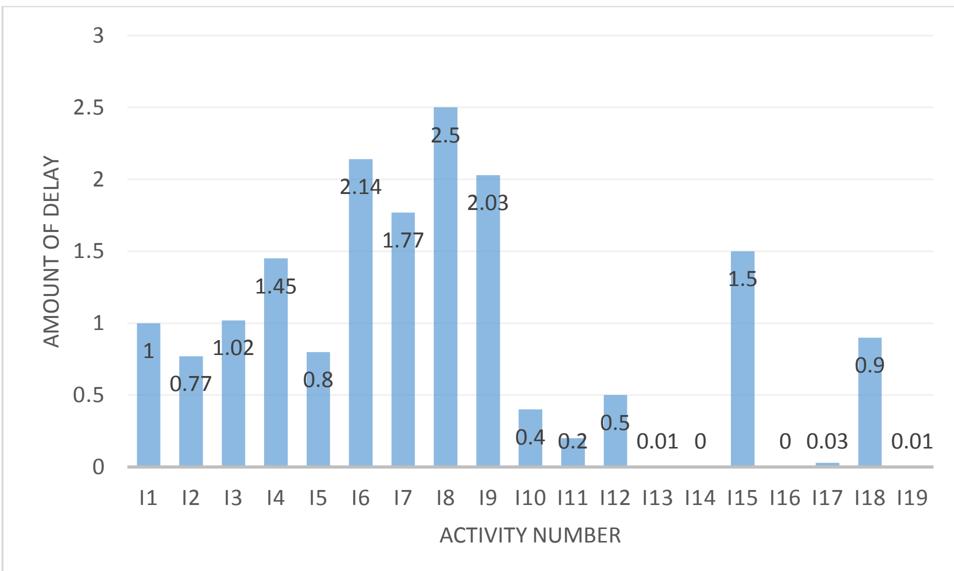

Fig 3. Comparison of optimal delay time in each network activity

The sum of the total delays is equal to 17.3-time units when activity 8 recorded the highest total delays. Regarding the allocation of strategies to each of the risks applied for each of the activities, you can refer to the table below. It is noteworthy that these allocations are related to primary risk.

Table 5. Response strategy to initial risk

Activity	Risks	strategies											
		K1	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**	**K11**	**K12**
I1	R1	1	1	1									
I1	R2	1	1	1									
I1	R3					1	1				1		
I1	R4				1	1	1						
I2	R5							1		1			1
I5	R1	1	1	1									
I5	R2	1	1	1									
I5	R3				1	1	1						
I7	R11					1					1		1
I8	R9				1						1	1	
I8	R15				1				1	1			
I8	R16			1	1	1							
I8	R23				1					1		1	
I9	R9											1	
I19	R23									1		1	

The numbers 1 in the table indicate the allocation of the relevant strategy to deal with the risk applied to each activity. Similarly, the allocation of strategies to secondary risks applied to activities can be shown as follows.

Table 6. Allocating strategies for dealing with each of the secondary risks applied to the activities

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

As it is clear from the table above, the response strategies that cost a lot compared to the existing risk have been removed, which shows the high efficiency of the model.

4-1-Sensitivity analysis

In this section, because the sensitivity analysis must be performed on a parameter that is a variable coefficient in the problem, for this reason, we will first perform the sensitivity analysis on the value of the response cost to the primary strategy, which is that the activities that are at risk If it has happened, we will change the cost of its response as follows:

Table 7. Values of cost and benefit of response to risk before and after the change

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

Now that the values in the above table are given, we want to see what effect it will have on the initial risk cost and the change in the allocated strategies, the results of which are shown in the following table:

Table 8. Values of cost and benefit of response to risk before and after the change

Objective function before change	Objective function after change
32.780	31.880

Table 9. Response strategy to the initial risk before changing the cost and benefit values of the response strategy

ا	Activity	strategies											
		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 10. Response strategy to the initial risk after changing the values of the cost and benefit of the response strategy

Activity	Risks	strategies											
		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						

Table 10. Continued

Activity	Risks	strategies											
		K1	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**	**K11**	**K12**
I9	R22										1		
I15	R23											0	1

As it is clear from the table above, after increasing the response cost, there has been a change in the optimal allocation strategy, which shows the correct performance of the model.

Now, to perform another validation to understand the performance of the model, we apply another change as follows:

Table 11. Values of changing the parameters of the response execution cost and time benefit

$caction_{111}$	**[0.1]** **[0.05]** **...**
$caction_{112}$	**[0.1]** **[0.2]** **…**
$etime_{112}$	**[4]** **[0.5]** **…**

Table 12. Response strategy to the initial risk after changing the cost values and the time and cost-benefit of the response strategy

Activity	Risks	strategies											
		K1	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**	**K11**	**K12**
I1	R1	0	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 it is clear in the table above, the applied changes made the strategy K1, the risk of R1, to be zero, and the strategy K2 to be one.

Now, after the sensitivity analysis that we did on the cost values, we want to show the maximum time that we can respond to the risks so that the cost of failure of activities becomes zero, which changes are as follows:

Table 13. Analysis of the table regarding the time frame and damage of failure

timespan	Initial risk cost	Cost of secondary risk	cost of failure
67	29.090	8.500	0.630
68	29.090	8.500	0.530
69	29.090	8.500	0.430
70	29.090	8.500	0.330
71	29.090	8.500	0.250
72	29.090	8.500	0.180
73	29.090	8.500	0.130
74	29.090	8.500	0.080
75	29.090	8.500	0.060
76	29.090	8.500	0.040
77	29.090	8.500	0.020
78	29.090	8.500	0

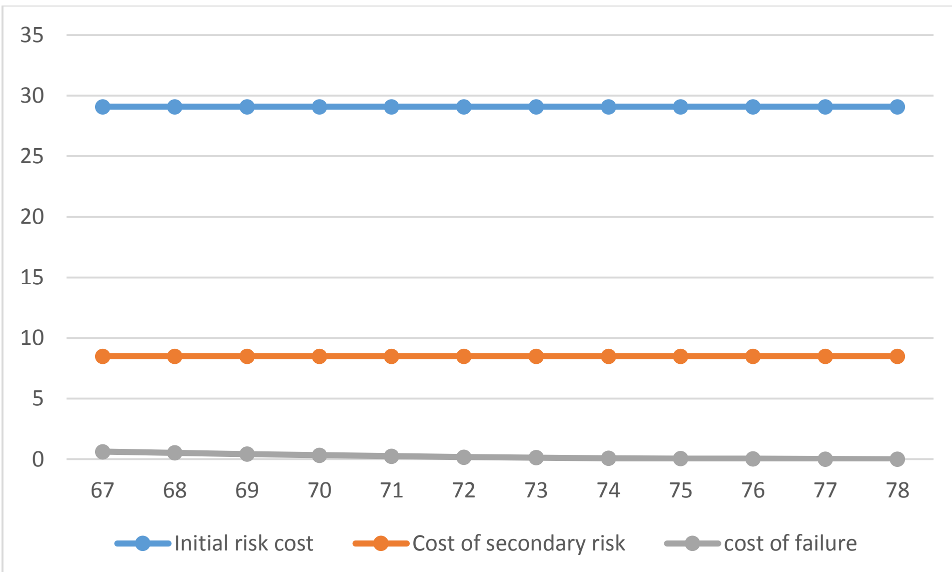

Fig 4. Changes in the failure function and the primary and secondary cost of the activities compared to the increase in the total project time.

As can be seen from the tables and figures above, the cost of failure of activities will be reduced to zero in 78 days, in fact, 78 is the maximum time when the project can be finished, and more than that, the amount of failure will be zero.

4-2-Examining numerical results using meta-heuristic algorithms

Based on the results presented in the previous sections, it can be said that the problem model can provide acceptable numerical results and the sensitivity analysis of the model has also confirmed this issue. But in this section, more extensive numerical analyzes will be applied to the results. As it is known, the Tabu search algorithm was able to give the right answer at the right time in high dimensions.

Table 14. Numerical results of solving numerical examples using different algorithms

	The dimension of the problem			GAMS answer	Tabu search	
Numerical examples	i	l	k	The objective function	The objective function	solution 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

It can be seen that by increasing the dimensions of the numerical examples, the game software is no longer able to solve the problem. In other words, if the dimensions of the numerical examples increase, the growth trend of the solution time also increases in proportion to the dimensions of the examples, which shows that the research case can be solved in high dimensions. The graph below shows the comparison between the solution time of different algorithms.

5 - Conclusion

In this research, 24 possible risks that were collected by experts were implemented on the activities of Steam Unit 2, and the first step that was taken was the implementation of strategies to respond to the initial risks, which were considered as In the results, it was found that the cost of the primary risk was reduced from 84,540 to 29,090, and also by responding to the primary risk, secondary risks were created, which caused a cost of 8,500 units to the system, but with the allocation of secondary strategies, this cost was reduced to 3.060 and also the optimal cost of activity failure was 0.630, but with the sensitivity analysis that was done, the maximum amount of time that the project can end is equal to 78 days, and more than that makes the cost of activity failure to be zero. Also in this The research used genetic meta-heuristic algorithm and Particle swarm to solve the problem in high dimensions, and the results showed that there is no difference in the results of these two algorithms.

How does mathematical modeling of risk response and choosing an optimal set of actions to respond to risks reduce risks and ensure that the project achieves its goals?

As stated in the fourth chapter, several strategies were assigned to a number of risks, and these optimal strategies and their effects are specified in the table 15.

Table 15. Optimal strategies assigned to primary risks

Activity	Risks	strategies											
		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

As it is clear from table (15), in this research, optimal primary and secondary strategies have reduced the level of risk, and appropriate measures for primary and secondary risk have reduced the level of risk.

Sub questions:

1- What is the optimal cost of the initial risk response strategy?

As it was determined from the results of the fourth chapter, the optimal amount of the initial risk was equal to 29,090, which made it possible to save 55 risk cost units from the total of 84,540 available risk units.

2- What is the optimal cost of the secondary risk response strategy?

As it was clear from the results of the fourth chapter, the value of secondary risk decreased from 8.500 to 3.060, which again shows the optimal effect of the model on reducing secondary risk.

3- What is the amount of the remaining optimal cost?

As it is clear from the definition of the residual risk, the residual risk is actually the amount of risk that exists in the model after responding to the primary and secondary risk, which as mentioned in the modeling of the third chapter, is in the form of equations in the objective and second functions and in the form The time and cost budget limits were formed in the model, and the model was optimized simultaneously with these definitions, so the remaining risk is included in the primary and secondary costs.

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