Designing the Optimal Choice of Risk Response with Consideration of Secondary Risks in a Wellhead Installation Project in the Oil and Gas industry

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Identification and designing appropriate risk response actions for secondary risks alongside primary risk management are gaining increasing attention from project managers. Considering the limited number of research on secondary risks, the main purpose of this article is to investigate the consequences of ignoring or considering secondary risks when selecting the optimum risk response actions for primary risks within a wellhead project in Iran. The main contribution of the present study is to identify the primary and secondary risks and their relations with the project main activities to provide the optimal set of response actions considering the secondary risks in small scale wellhead project in the oil and gas industry in Iran. Cost minimization models through integer linear programming optimization were solved considering the secondary risks in selecting risk responses. The results indicate that considering the secondary risks can affect the selection of optimal risk response actions. Although considering secondary risks could increase the total cost of risks by 6,342 dollars, however, neglecting the secondary risks could result in selecting responses that cause more costs around 26,408 dollars. The present study might help project managers to manage their small-scale project risks better and avoid further losses.

Keywords: *Project Risk Management; Risk Response Action; Secondary Risk; Optimization; Oil & Gas Industry.*

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Nomenclature

i	An index i for each variable refers to a member of the set of activities
l	Index l, if it comes to variables related to primary risk, it refers to a member of the group of primary risks; otherwise, it refers to a member of the group of secondary risks.
k	Index k, if it comes to variables related to primary risk, refers to a member of the set of primary responses; otherwise, it refers to a member of the group of secondary response.
$Cost_{primary}$	Primary risk cost
$Cost_{secondary}$	Secondary risk cost
$Cost_{crash}$	Total crash cost
c_i^{crash}	crash cost
c_{ilk}^{action}	Cost of primary RRA
$c_{ilk}^{s\,action}$	Cost of secondary RRA
$d_i^{primary}$	Primary time delays
$d_i^{secondary}$	Secondary time delays
d_i	Normal time
d_i^{min}	Minimal time
Xi	Number of days for crashing
y_{ilk}	Primary decision variable
y_{ilk}^{s}	Secondary decision variable
d_i^{risk}	Time delay
q_{il}^{cost}	Primary expected loss
q_{il}^{time}	Primary expected delay
e_{ilk}^{cost}	Primary cost improvement amount

e_{ilk}^{time}	Primary time improvement amount
q_{ilk}^{stime}	Secondary expected delay
e_{ilk}^{stime}	Secondary time improvement amount
$q_{ilk}^{s\cos t}$	Secondary expected loss
$e_{ilk}^{s\cos t}$	Secondary cost improvement amount
q_i^*	Threshold value
d_i^*	Predefined value
$T_{successor}$	Early start time of the successor activities
$T_{predessor}$	Early start time of predecessor activities
T_t	Total project time
T_n	Deadline project time
NC	Normal Constraint
VIF	Variance Inflation Factor

1. Introduction

A risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives, which must be managed. Risk management has several phases, including planning risk response, which is a process that determines effective response actions [1]. Creating the risk response action plan (RRA) is a crucial phase in project risk management. It is also important to note that less effective response strategies can lead to higher costs [2], and sometimes, responding to primary risk leads to serious new risks, known as secondary risks [1]. Thus, identification and designing optimal risk response action to manage secondary risks seems necessary.

Due to intensive investment, the presence of different stockholders, complexity in design, planning, and technology, unique nature, limited resources, and weather patterns, oil and gas projects are composed of high risks [3, 4]. The wellhead installation project is carried out to exploit natural gas. The end of drilling and installation of equipment in the well is the beginning of the wellhead installation project.

The main motivation for this research is to identify the primary and secondary risks and design appropriate risk response actions in an expensive and risky wellhead facilities installation project in the oil and gas industry. Although considering secondary risks may lead to increased costs, it is crucial for project managers of these types of risky projects to manage their small-scale project risks better and avoid further losses.

Thus, this study aims to provide a framework for the selection of the optimal set of response actions considering the most relevant secondary risks.

1.1. Research Background

The idea of secondary risk in project management literature goes back to a seminal paper by Chapman in 1979 [5]. Bai et al., [6] introduced a multi stage model consists of primary and secondary risk management in 2001. As they explained, the secondary risk analysis is necessary to ensure that the losses of primary risk management are less than the losses of primary risks. Cummings et al., [7] argued that comparing to the protection motivation theory, secondary risk theory better explains the vaccination intention when individuals predicts some side effects after vaccination.

Naji and Ali [8] studied the process of risk response selection in construction projects. The process includes finding the projects in which risk responses failed, the second part involves the reasons for the failure of the risk response, and the third part consists finding the most critical risks caused by the response. The results of the third part showed that the most important secondary risks were; delay in disbursing advances to contractors, delay of the projects, delayed implementation of commitments, wrong estimation, and depressions. The fourth part is choosing the optimal strategy to respond to risk through the Gravitational search algorithm and the Particle Swarm method. They concluded that both methods are highly efficient.

Namazian and Behboodian [9] classified three main categories of risk response strategy modelings including Zonal-based, Trade-off-based, WBS, and optimization approach. They applied the zero-one programming to minimize the cost of implementation in refinery construction with three main activities, six risks and 12 risk response strategies. They concluded that selecting appropriate set of response strategies decrease the time and costs of the project.

Zuo and Zhang [10] identified primary risks, responses, and secondary risks for a construction project in a double-story island platform station and two parallel tunnels. Based on the optimization model, they found that project managers need to allocate more funds to respond to risk considering secondary risk, and to choose the appropriate primary and secondary RRA, they must consider all factors related to time and costs.

Zhang and Sun [11] presented a suitable tool for choosing the optimal primary and secondary risk response strategy for railway safety managers in the case of train derailment by using the DIMATEL, ANP (Analytical Network Process), and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods.

Asl Tabatabay and Asl Tabatabay [12] created a model to select the optimal responses to primary and secondary risks in the 800-ton tower transportation and installation project. Using the genetic algorithm, they showed that with the consideration of secondary risks and appropriate strategies, the cost of risk responses was reduced.

Parsaei Motamed and Bamdad [13] used the branch and bound method to achieve primary and secondary optimal responses regarding environmental risks. They concluded that to achieve optimal responses paying attention to secondary risk is very effective, and the sensitivity of the objective function to the cost factor is more than those for the time and quality factors.

Ghadir et al. [14] stated that risk management could provide a solution to the challenge of the uncertainty of time and cost estimation in industrial projects; therefore, they presented an optimization model to respond to the primary, secondary, and residual risks and solved it with the Tabu algorithm. They found that the consideration of the secondary risks and designing appropriate response strategies can reduce the cost and level of risks to the optimum level.

Focusing on the secondary risk reduction in the Italian nuclear decommissioning projects through Single Objective Optimization Model showed that the consideration of secondary risks reduce time delay and overall implementation costs [15].

In order to minimize the unsatisfied demand and dissatisfaction of passengers, Ghanbari et al., (2023) applied a robust integer optimization model and showed that the selection of primary risk responses is significantly influenced by secondary risk [16].

Ahmadi et al., [17] suggested a multi-objective (cost, quality, and time) fuzzy model to address the issue of primary/ secondary risks in projects. The results revealed that the consideration of secondary risks alters the optimal set of risk response actions, and some actions in response to primary risks should be eliminated.

Zou and Zio [18] applied a mixed-integer optimization model to investigate the optimal risk response strategies for secondary risks when project managers have resource and time constraints. The results showed that secondary risk reduction enhances the project performance.

In summary, the literature review showed that the authors in the project management field used many different methods, such as optimization models, fuzzy theory, and ANP in various projects such as building, construction of highways, transportation, and installation of towers to offer the best framework on the risk response strategies. However, it seems that the previous researches on the secondary risk have not considered different types of relationships between main activities and primary/ secondary risks which we addressed in the current study. Furthermore, we contribute to the existing literature by focusing on the optimal choice of risk response actions with the consideration of secondary risks in the new context of a complex and costly wellhead installation project in the oil and gas industry in Iran.

1.2. Research Context

In order to identify the main activities, and collect the data on the relevant primary and secondary risks, risk response actions, and the related time and costs, we chose a wellhead installation project from the company S, located in southwest of Iran. This company is one of the three subsidiaries of the Iranian Central Oil Fields Company that produces part of natural gas for consumption in Iran. The company operates in several oil and gas fields and the selected project is carried out in Tabnak natural gas field in southern Fars province.

2. Methodology

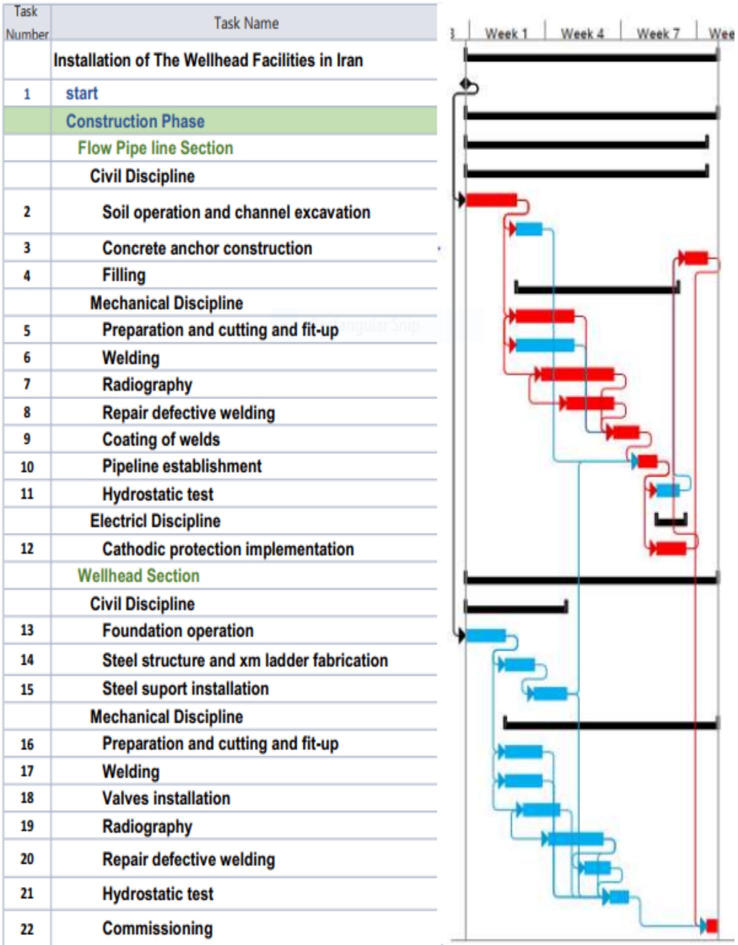
There are two main steps in conducting this research. Step one includes identifying main activities, primary and secondary risks, risk responses, and related values in the wellhead installation project. Step two consist of solving the model in two modes with or without considering secondary risks.

Although the formulations of the optimization model were mainly drawn from the Zuo & Zhang (2018) [10], the superiorities of our proposed framework in comparison with the previous research are twofold: to the best of our knowledge the current study is the first study on wellhead installation project in oil and gas industry. Moreover, from the methodology perspective, unlike the previous research, we studied different types of relationships between main activities and primary/ secondary risks through WBS and expert judgment in a mixed-integer linear optimization model.

2.1. Main activities, primary and secondary risks, and risk responses in the wellhead installation project

Due to lack of the necessary archival data within the company, the interview method, activity-related method through Work breakdown structure. Expert judgment also are used to collect the data. Nine experts from the company that have been active in this field, agreed to be interviewed.

Through the WBS analysis and expert interview 22 main activities from Start to Commissioning were identified. Predecessor, normal time, minimal time, and crash costs have been collected for these activities. Gant chart in the construction phases of wellhead facilities installation project is shown in Fig 1.



Task Number	Task Name
	Installation of The Wellhead Facilities in Iran
1	start
	Construction Phase
	Flow Pipe line Section
	Civil Discipline
2	Soil operation and channel excavation
3	Concrete anchor construction
4	Filling
	Mechanical Discipline
5	Preparation and cutting and fit-up
6	Welding
7	Radiography
8	Repair defective welding
9	Coating of welds
10	Pipeline establishment
11	Hydrostatic test
	Electricl Discipline
12	Cathodic protection implementation
	Wellhead Section
	Civil Discipline
13	Foundation operation
14	Steel structure and xm ladder fabrication
15	Steel suport installation
	Mechanical Discipline
16	Preparation and cutting and fit-up
17	Welding
18	Valves installation
19	Radiography
20	Repair defective welding
21	Hydrostatic test
22	Commissioning

Fig. 1. Gant Chart of the installation of wellhead installation project

Based on the project activities and expert interviews, seventeen primary risks, thirteen primary responses, four secondary risks, and three secondary responses were identified and shown in Tables 1, 2, 3, and 4 respectively.

Table 1. Identified primary risk

Risk ID	Primary risk
R1	Machinery failure
R2	Run out of fuel
R3	Prolonged pipe repairs
R4	Scour erosion
R5	Creating pressure on the pipes that are under the road
R6	Corrosion of insulation
R7	Crane belt rapture

R8	Cutting plate fracture
R9	wind blowing
R10	Humidity and rainfall
R11	decay of the electrode
R12	decay of coting of welds
R13	Hydrostatic pump burst
R14	Insufficient strength of concrete
R15	Incompatibility of design and execution armature type
R16	The hand wheel of the valves does not rotate
R17	Pipe leakage

Table 2. Identified primary RRA

RRA ID	Primary RRA
A1	The presence of skilled repair work on the site
A2	Use of fuel reservoir
A3	Using concrete slabs
A4	DCVG test
A5	Inspection
A6	Preparation of high-quality cutting plate
A7	Use of went
A8	Maintenance according to standard
A9	Preparation of hydrostatic pump with a higher pressure tolerance
A10	Radiograph after welding repair
A11	Checking the design of mixing concrete materials
A12	Applying more pressure using a pipe wrench
A13	Greasing

Table 3. Identified Secondary Risk

Risk ID	Secondary Risk
SR1	Fire
SR2	Device malfunction
SR3	Standard ignorance
SR4	Breaking the bearing

Table 4. Identified Secondary RRA

Secondary RRA ID	Secondary RRA
SA1	Use of fire extinguisher and fire alarm system
SA2	Inspection
SA3	Both sides representative periodic supervision of the warehouse environment

It should be noted that only the risks that have a negative effect on the project within the categories of technical and external risks are identified. It is also important to note that each risk is considered independently.

2.1. Optimization model

There are several competing optimization models in the literature to choose from. However, depend on the nature of objective function and constraints (single or multiples, linear or non-linear, stochastic or non-stochastic), a researcher should decide on the appropriate model. The main advantages of the mixed-integer linear formulation are the generation of a globally optimal solution (no better local solution), the accuracy of the results, and available solvers [19, 20], which leads to wide application of the MILP optimization in recent publications [e.g.9, 10, 16, 18].

Considering the above mentioned criteria, we applied the mixed integer linear programming model to minimize the total cost, which is obtained from the cost of primary risks, secondary risks, and crash costs. The optimization model, described below, is solved by Lingo software version 11 through the branch and bound algorithm.

2.2 Objective Function

The objective function and the sub-functions are specified by the formulas (1)-(4), respectively.

$$\min z = Cost_{primary} + Cost_{secondary} + Cost_{crash} \qquad (1)$$

$$Cost_{primary} = \sum_{i}\sum_{l} q_{il}^{cost} - \sum_{i}\sum_{l}\sum_{k} e_{ilk}^{cost} y_{ilk} + \sum_{i}\sum_{l}\sum_{k} c_{ilk}^{action} y_{ilk} \qquad (2)$$

$$Cost_{secondary} = \sum_{i}\sum_{l}\sum_{k} q_{ilk}^{s\,cost} y_{ilk} - \sum_{i}\sum_{l}\sum_{k} e_{ilk}^{s\,cost} y_{ilk}^{s} + \sum_{i}\sum_{l}\sum_{k} c_{ilk}^{s\,action} y_{ilk}^{s} \qquad (3)$$

$$Cost_{crash} = \sum_{i} c_{i}^{crash} x_{i} \qquad (4)$$

To calculate primary and secondary costs, the data on probability, time, expected delay, expected loss, costs of primary and secondary RRAs , time improvements, and costs improvement estimation were collected from the experts.

2.3 Model constraints

The constraints include cost, time, and decision variable constraints as follows:

Cost constraints: According to this constraint, the cost of the primary risk is higher than or equal to the secondary risk cost because the risk cost should be reduced to select the optimal risk response actions, which is expressed in (5).

$$Cost_{primary} \geq Cost_{secondary} \quad \textbf{(5)}$$

Residual risks should be less than or equal to the threshold value determined by (6).

$$\sum_{l} q_{il}^{cost} - \sum_{l}\sum_{k} e_{ilk}^{cost} y_{ilk} + \sum_{l}\sum_{k} q_{ilk}^{scost} y_{ilk} - \sum_{l}\sum_{k} e_{ilk}^{scost} y_{ilk}^{s} \leq q_i^{*} \quad \textbf{(6)}$$

Time constraints: The total risk delay is equal to the delay caused by the primary risk plus the delay due to the secondary risks that are formulated by (7)-(9), respectively.

$$d_i^{risk} = d_i^{primary} + d_i^{secondary} \quad \textbf{(7)}$$

$$d_i^{primary} = \sum_{l} q_{il}^{time} - \sum_{l}\sum_{k} e_{ilk}^{time} y_{ilk} \quad \textbf{(8)}$$

$$d_i^{secondary} = \sum_{l}\sum_{k} q_{ilk}^{stime} y_{ilk} - \sum_{l}\sum_{k} e_{ilk}^{stime} y_{ilk}^{s} \quad \textbf{(9)}$$

The delay due to the secondary risks must be lower than or equal to the delay caused by the primary risk as determined by (10).

$$d_i^{primary} \geq d_i^{secondary} \quad \textbf{(10)}$$

Because it is necessary to ensure that the time delays caused by risks are limited to a predefined value and the integer number of days for crashing activities needs to be less than the maximum number of days that can be crashed, constraints (11) and (12) are incorporated in the model:

$$0 \leq d_i^{risk} \leq d_i^{*} \quad \textbf{(11)}$$

$$0 \leq x_i \leq d_i - d_i^{min} \quad \textbf{(12)}$$

The constraint relevant to the earliest start time of the successor and predecessor activities is as follows: if the relationship between activities is FS type should be specified by (13), and if it is SS type it should be specified by (14).

$$T_{successor} \geq \{T_{predessor} + d_{predecessor} + d_{predecessor}^{risk} - x_{predecessor} \pm lag\}, T_1 = 0 \quad \textbf{(13)}$$

$$T_{successor} \geq \{T_{predessor} \pm lag\}, T_1 = 0 \quad \textbf{(14)}$$

The total project time should be less than or equal to the time specified by the expert (15):

$$T_t \leq T_n \quad \textbf{(15)}$$

Decision variable constraints: The decision variable related to the secondary risk can be selected when the decision variable related to the primary risk is selected. The binary decision variables are modeled by (16).

$$y_{ilk} \geq y_{ilk}^{s} \ , \ \ y_{ilk}, y_{ilk}^{s} \in \{0,1\} \quad \textbf{(16)}$$

As mentioned, the model is solved in two modes, with or without considering the secondary risks. Where secondary risks are not considered, the variables related to secondary risks are removed from the equations.

3. Results

3.1 Main Activities, Risks and Responses

Table 5 shows that there are 22 main activities to install wellhead facilities. The table also portrays the information related to activities such as normal time, minimum time, predecessor, and crash cost, which are obtained from the company's experts.

Table 5. The activities of the wellhead facilities installation project

Task ID	Task Name	Predecessor	Normal Time (day)	Minimal Time (day)	Crash Cost (dollar/day)
I1	Start	-	0	0	0
I2	Soil operation and channel excavation	I1	14	10	753.62
I3	Concrete anchor construction	I2	7	5	696.35
I4	Filling	I11,I12	6	3	145.70
I5	Preparation and cutting and fit-up of flow pipeline	I2	16	11	200.15
I6	Welding of flow pipeline	I5SS	16	11	210.26
I7	Radiography of flow pipeline	I5SS+7	20	15	154.55
I8	Repair defective welding of flow pipeline	I7SS+7	13	5	51.56
I9	Coating of welds of flow pipeline	I5,I6,I7,I8	7	4	101.96

I10	Pipeline Establishment of flow pipeline	I9,I15,I3	5	3	72.22
I11	Hydrostatic test of flow pipeline	I10	6	4	465.47
I12	Cathodic protection implementation	I10	8	5	249.61
I13	Foundation operation	I1	11	7	484.11
I14	Steel structure and XM ladder fabrication	I13	8	6	202.05
I15	Steel support installation	I14	9	6	126.59
I16	Preparation and cutting and fit-up of wellhead	I13	10	7	99.76
I17	Welding of wellhead	I16SS	10	7	91.48
I18	Valves installation of wellhead	I17SS+5	10	6	68.16
I19	Radiography of wellhead	I18SS+7	15	11	70.09
I20	Repair defective welding of wellhead	I19FS-5	7	3	38.63
I21	Hydrostatic test of wellhead	I15,I16,I17,I8,I19,I20	5	4	58.07
I22	Commissioning	I4,I21	3	2	47.39

The relationships among the activities and risks and responses are specified in Table 6. The table shows that for 9 activities, relationships between primary risks, secondary risks and the relevant risk response action were existed. For example, no risk has been identified for activity I7, while two risks (R1, R2) have been identified for activity I10.

Table 6. Relationships between activities and risks and responses

Task id	Primary risk	Primary RRA	Secondary risk	Secondary RRA
I1				
I2	R1	A1		
	R2	A2	SR1	SA1
I3	R3			
I4	R4			
	R5	A3		
	R6	A4	SR2	SA2
I5	R7	A5		
	R8	A6		
I6	R9	A7		
	R10			
	R11	A8	SR3	SA3
		A5		
I7				
I8	R9	A7		
	R10			
	R11	A8	SR3	SA3
		A5		
I9	R12	A8	SR3	SA3
I10	R1	A1		
	R2	A2	SR1	SA1
I11	R13	A9		
	R17	A10		
I12	R6	A4	SR2	SA2
I13	R14	A11		
	R15	A5		
I14				
I15				

I16	R7	A5		
	R8	A6		
I17	R9	A7		
	R10			
	R11	A8	SR3	SA3
		A5		
I18	R16	A12	SR4	
		A13		
I19				
I20	R9	A7		
	R10			
	R11	A8	SR3	SA3
		A5		
I21	R13	A9		
	R17	A10		
I22				

Tables 7, 8, 9 and 10 lists the data required for modeling related to risks and responses.

Table 7. The Information on Primary Risks

Task ID	Risk ID	Primary probability	Primary time impact (day)	Primary cost impact (dollar)	Primary expected delay	Primary expected loss (dollar)
I2	R1	0.3	5	3,031.76	1.5	909.53
I2	R2	0.75	6	2,770.23	4.5	2,077.67
I3	R3	0.55	3	9,910.12	1.65	5,450.57
I4	R4	0.1	2	2,499.96	0.2	250.00
I4	R5	0.65	6	13,066.67	3.9	8,493.33
I4	R6	0.35	7	8,956.63	2.45	3,134.82
I5	R7	0.05	3	821.51	0.15	41.08
I5	R8	0.3	3	1,486.98	0.9	446.09
I6	R9	0.2	2	698.02	0.4	139.60
I6	R10	0.4	4	1,932.98	1.6	773.19
I6	R11	0.6	4	3,261.85	2.4	1,957.11
I8	R9	0.2	2	698.02	0.4	139.60
I8	R10	0.4	4	1,932.98	1.6	773.19
I8	R11	0.6	4	2,259.85	2.4	1,355.91
I9	R12	0.7	5	2,949.13	3.5	2,064.39
I10	R1	0.3	4	2,074.75	1.2	622.43
I10	R2	0.75	4	1,771.72	3	1,328.79
I11	R13	0.05	3	3,328.18	0.15	166.41
I11	R17	0.03	6	4,098.39	0.18	122.95
I12	R6	0.25	7	8,956.63	1.75	2,239.16
I13	R14	0.06	7	22,724.06	0.42	1,363.44
I13	R15	0.1	5	2,292.42	0.5	229.24
I16	R7	0.1	3	712.25	0.3	71.22
I16	R8	0.3	3	1,308.32	0.9	392.50
I17	R9	0.2	2	570.61	0.4	114.12
I17	R10	0.4	4	1,755.72	1.6	702.29
I17	R11	0.6	4	2,244.58	2.4	1,346.75
I18	R16	0.35	2	1,152.35	0.7	403.32
I20	R9	0.2	2	570.61	0.4	114.12
I20	R10	0.4	4	1,755.72	1.6	702.29
I20	R11	0.6	4	1,861.20	2.4	1,116.72
I21	R13	0.05	3	3,299.36	0.15	164.97
I21	R17	0.04	5	3,466.61	0.2	138.66

Table 7 provides information such as probability and time impact, cost impact, expected delay, and expected loss for each risk associated with an activity. The expected values for the expected delay (which is obtained by multiplying 0.75 by 6) and expected loss (which is obtained by multiplying 0.75 by 2,770.23). Table 8 shows the cost of RRA, time improvement, and cost improvement related to primary risks.

Table 8. The Information on Primary RRA

Task ID	Risk ID	RRA ID	Cost of primary RRA (dollar)	Primary time improvement	Primary cost improvement amount (dollar)
I2	R1	A1	853.104	1	227.382
I2	R2	A2	1833.333	4	1807.577
I4	R5	A3	3276.836	3	6794.667
I4	R6	A4	3000.000	2	1567.411
I5	R7	A5	60.000	0.05	14.376
I5	R8	A6	826.667	0.6	200.743
I6	R9	A7	67.500	0.1	6.980
I6	R11	A5	60.000	0.05	293.566
I6	R11	A8	412.333	2	978.554
I8	R9	A7	67.500	0.1	6.980
I8	R11	A5	60.000	1	67.796
I8	R11	A8	412.333	2	677.956
I9	R12	A8	412.333	3	1445.075
I10	R1	A1	280.224	0.5	155.606
I10	R2	A2	1020.000	3	1156.046
I11	R13	A9	2750.000	0.1	133.127
I11	R17	A10	2513.285	0.1	98.361
I12	R6	A4	3000.000	0.8	1119.579
I13	R14	A11	172.000	0.2	954.410
I13	R15	A5	60.000	0.3	103.159
I16	R7	A5	60.000	0.05	42.735
I16	R8	A6	413.333	0.6	176.624
I17	R9	A7	67.500	0.1	6.847
I17	R11	A5	60.000	1	67.337
I17	R11	A8	412.333	2	673.374
I18	R16	A12	15.500	0.4	201.661
I18	R16	A13	58.667	0.6	302.491
I20	R9	A7	67.500	0.1	6.847
I20	R11	A5	60.000	1	55.836
I20	R11	A8	412.333	2	558.359
I21	R13	A9	2750.000	0.1	131.975
I21	R17	A10	1884.964	0.1	110.931

Table 9 provides information related to secondary risks, such as the probability of occurrence of SR1 in activity i2.

Table 9. The Information on Secondary Risk

Task ID	Risk ID	RRA ID	Secondary Risk ID	Secondary probability	Secondary time impact (day)	Secondary cost impact (dollar)	Secondary expected delay (day)	Secondary expected loss (dollar)
I2	R2	A2	SR1	0.3	20	27,237.10	6	8,171.13
I4	R6	A4	SR2	0.08	4	7,888.43	0.32	631.07
I6	R11	A8	SR3	0.7	4	3,261.85	2.8	2,283.29
I8	R11	A8	SR3	0.7	4	2,259.85	2.8	1,581.90
I9	R12	A8	SR3	0.7	4	2,949.13	2.8	2,064.39
I10	R2	A2	SR1	0.3	20	27,237.10	6	8,171.13
I12	R6	A4	SR2	0.08	4	7,288.43	0.32	583.07
I17	R11	A8	SR3	0.7	4	2,244.58	2.8	1,571.21
I18	R16	A12	SR4	0.5	7	15,776.02	3.5	7,888.01
I20	R11	A8	SR3	0.7	4	1,861.20	2.8	1,302.84

Table 10 provides information related to secondary risk response action.

Table 10. The Information on Secondary RRA

Task ID	Risk ID	RRA ID	Secondary Risk ID	Secondary RRA ID	Cost of secondary RRA (dollar)	Secondary cost improvement amount (dollar)	Secondary time improvement amount
I2	R2	A2	SR1	SA1	379.34	4902.68	4
I4	R6	A4	SR2	SA2	100.00	315.54	0.2
I6	R11	A8	SR3	SA3	93.33	1202.24	2
I8	R11	A8	SR3	SA3	93.33	1202.24	2
I9	R12	A8	SR3	SA3	93.33	1568.94	2
I10	R2	A2	SR1	SA1	379.34	4902.68	4
I12	R6	A4	SR2	SA2	100.00	291.54	0.2
I17	R11	A8	SR3	SA3	93.33	1194.12	2
I20	R11	A8	SR3	SA3	93.33	990.16	2

The threshold value and the predefined value are shown in Table 11. Activities for which no risk identified have zero values, such as activity I1.

Table 11. Province values associated with each activity

Task ID	Threshold value (dollar)	Predefined value (day)
I1	0.00	0
I2	2987.20	5
I3	5450.57	1.65
I4	11628.15	7
I5	487.17	2
I6	2730.30	8
I7	0.00	0
I8	2129.11	8
I9	3633.33	5
I10	1951.21	4
I11	422.49	4
I12	2822.23	5
I13	1592.69	8
I14	0	0
I15	0	0
I16	463.72	6
I17	2049.04	8
I18	806.64	4
I19	0.00	0
I20	1819.01	8
I21	303.63	0.35
I22	0.00	0

3.2 Model Solution Output

Assuming that T_n is equal to 70 days, the following results have been obtained by solving the model.

Table 12. Primary RRA selected

ID	y (first mode: no 2ndary risk consideration)	y (second mode: with 2ndary risk consideration)
I2 ,R1 ,A1	0	1
I2 ,R2 ,A2	1	0
I4 ,R5 ,A3	1	1
I4 ,R6 ,A4	0	0
I5 ,R7 ,A5	0	0
I5 ,R8 ,A6	0	0
I6 ,R9 ,A7	0	0
I6 ,R11 ,A5	1	1
I6 ,R11 ,A8	1	0
I8 ,R9 ,A7	0	0
I8 ,R11 ,A5	1	1
I8 ,R11 ,A8	1	1
I9 ,R12 ,A8	1	0
I10 ,R1 ,A1	0	1
I10 ,R2 ,A2	1	0
I11 ,R13 ,A9	0	0
I11 ,R17 ,A10	0	0
I12 ,R6 ,A4	0	0
I13 ,R14 ,A11	1	1

I13 ,R15 ,A5	1	1
I16 ,R7 ,A5	0	0
I16 ,R8 ,A6	0	0
I17 ,R9 ,A7	0	0
I17 ,R11 ,A5	1	1
I17 ,R11 ,A8	1	1
I18 ,R16 ,A12	0	0
I18 ,R16 ,A13	1	1
I20 ,R9 ,A7	0	0
I20 ,R11 ,A5	0	0
I20 ,R11 ,A8	1	1
I21 ,R13 ,A9	0	0
I21 ,R17 ,A10	0	0

As shown in Table 12, according to budget and time constraints and other issues (such as primary and secondary risk cost impact), a series of responses have been selected as optimal responses in both modes, and a series of responses have been selected in one mode and not selected in the other mode. A series of responses were also not selected in both modes.

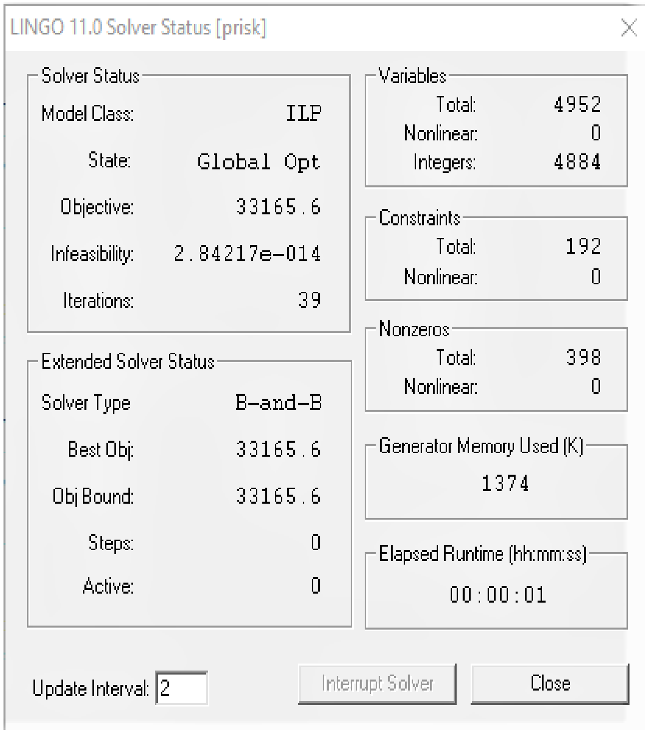
Considering the budget and time constraints for the secondary responses, only SA3, which was related to SR3 in I8, I17, and I20 activities, has been selected (Table 13).

Table 13. The selected Secondary RRA

ID	y^s
I2,R2,A2,SR1,SA1	0
I4,R6,A4,SR2,SA2	0
I6,R11,A8,SR3,SA3	0
I8,R11,A8,SR3,SA3	1
I9,R12,A8,SR3,SA3	0
I10,R2,A2,SR1,SA1	0
I12,R6,A4,SR2,SA2	0
I17,R11,A8,SR3,SA3	1
I20,R11,A8,SR3,SA3	1

Figures 2 and 3 show the results of the estimated objective function (cost minimization). When only the primary risks are considered (first mode), the cost is $33,165.6, while the primary and secondary risks are considered (second mode), the cost is $39,507.6.

The total cost difference between the two modes is 6,342 dollars.



Solver Status
Model Class: ILP
State: Global Opt
Objective: 33165.6
Infeasibility: 2.84217e-014
Iterations: 39

Extended Solver Status
Solver Type B-and-B
Best Obj: 33165.6
Obj Bound: 33165.6
Steps: 0
Active: 0

Variables
Total: 4952
Nonlinear: 0
Integers: 4884

Constraints
Total: 192
Nonlinear: 0

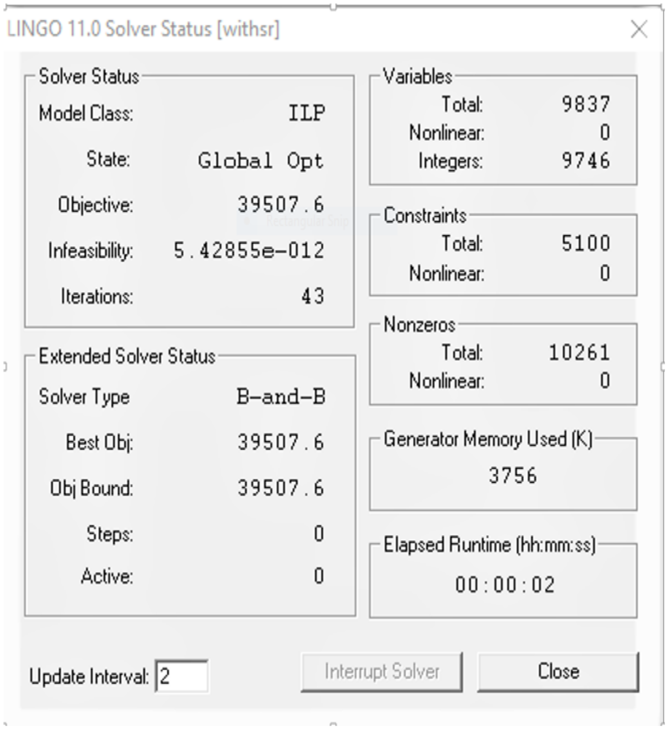
Nonzeros
Total: 398
Nonlinear: 0

Generator Memory Used (K)
1374

Elapsed Runtime (hh:mm:ss)
00:00:01

Update Interval: 2

Fig. 2. Lingo output in the first mode



Solver Status
Model Class: ILP
State: Global Opt
Objective: 39507.6
Infeasibility: 5.42855e-012
Iterations: 43

Extended Solver Status
Solver Type B-and-B
Best Obj: 39507.6
Obj Bound: 39507.6
Steps: 0
Active: 0

Variables
Total: 9837
Nonlinear: 0
Integers: 9746

Constraints
Total: 5100
Nonlinear: 0

Nonzeros
Total: 10261
Nonlinear: 0

Generator Memory Used (K)
3756

Elapsed Runtime (hh:mm:ss)
00:00:02

Update Interval: 2

Fig. 3. Lingo output in the second mode

3.3 Loss Due to Neglecting the Secondary Risk

In order to clarify the reason why the secondary risk was taken into account when choosing the primary responses, Table 15 was prepared.

To determine the consequences of these responses' selections, we considered three values namely A, B, and C.

The value of A indicates that consider only the primary values (primary risks and primary responses) and assume that secondary risks do not occur.

$$A = q_{il}^{cost} + c_{ilk}^{action} - e_{ilk}^{cost} \tag{17}$$

The value of B indicates that the secondary risk will occur, but no response has been considered for them, which is obtained from the sum of the value of A plus the secondary expected loss.

$$B = A + q_{ilk}^{scost} \tag{18}$$

The value of C indicates that it is assumed that the secondary risk occurs and the response is considered for them, which is obtained from the sum of the value of B plus the cost of the secondary response minus the secondary improvement.

$$C = B + c_{ilk}^{saction} - e_{ilk}^{scost} \tag{19}$$

If all similar values are added together, the total value is obtained.

Table14. Consequences of responses that should not be chosen

Responses	A	B	C
I2,R2,A2	2103.43	10,274.56	5751.22
I6,R11,A8	1390.89	3,674.18	2565.27
I9,R12,A8	1031.65	3,096.04	1620.43
I10,R2,A2	1192.74	9,363.87	4840.53
Total	5,718.71	**26,408.66**	14,777.5

Table 14 shows the consequences of the responses chosen in the first mode but should not be chosen according to the second mode. According to Table 14, the total value of A, B, and C are equal to $5718.71, $26408.66, and $14777.5, respectively. A means, if the responses that should not be selected according to the second mode were selected and secondary risk did not occur for them, they create about $5718.71 costs, and B: if secondary risk occurred and the response was not considered for them, it creates $26,408.66 costs). Moreover, C means if the secondary risk occurs and the response was considered for them, it creates $14,777.5 costs.

Considering the results of the estimated optimal cost functions (Fig2, Fig3) and Table 14, we can conclude that although considering secondary risks could increase the total cost of risks by 6,342 dollars, however, neglecting the secondary risks could result in selecting responses that cause more costs around 26,408 dollars.

3.4 Time-Cost Trade Off Analysis

The costs of the crash, the risk, and the total costs have been taken into consideration for the trade-off analysis of time and cost between 65 and 100 days. The cost of risk in the first mode is equal to the primary cost, but in the second mode, it is equivalent to the sum of the primary and secondary costs.

Table 15. Time-cost trade off

Day	Total cost (first mode)	Total cost (second mode)	Crash cost (first mode)	Crash cost (second mode)	Risk cost (first mode)	Risk cost (second mode)
65	34196.1	43616.6	2068.5	5831.8	32127.6	37784.8
70	33165.6	39507.6	1037.9	3570.9	32127.6	35936.6
75	32524.5	37799.0	396.9	1862.4	32127.6	35936.6
80	32175.0	36828.9	47.4	892.2	32127.6	35936.6
85	32127.6	36231.6	0.0	295.0	32127.6	35936.6
90	32127.6	35936.6	0.0	0.0	32127.6	35936.6
95	32127.6	35936.6	0.0	0.0	32127.6	35936.6
100	32127.6	35936.6	0.0	0.0	32127.6	35936.6

According to Table 15, all three types of costs in the second mode are higher than those in the first mode.

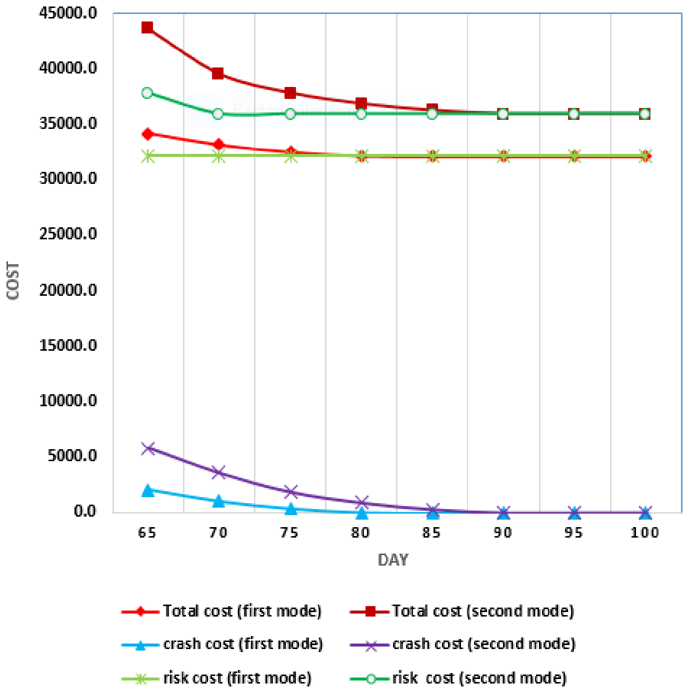


Fig. 4. Time-cost curve

Based on Fig 4, the optimal amount for the total cost is achieved in the first mode when the project time is 85 days and in the second mode when it is 90 days. By adding 20 days (the optimal time difference between the initial project time and the optimal time), the improvement in the total cost of risk is $3,570.9 in the second mode.

Checking the robustness of the results

Our findings are in line with Zuo and Zhang's (2018) research [10], which showed that the budget that should be considered for the second mode is more, and also confirmed Parsaei et al.,(2022) conclusion that if secondary risks are not taken into account, the budget allocated to the risk management process can be different from the actual requirement budget, and this can cause many problems during project implementation [13]. In addition to the findings of previous research, the results were confirmed by two experts in the civil and risk management fields.

4. Conclusions and recommendations

The stage of the risk response plan is one of the essential stages in risk management. Current research provides an optimization model to select the optimal risk response in the wellhead installation project in the oil and gas industry in Iran.

After identifying seventeen primary risks, thirteen primary RRA, four secondary risks, and three secondary RRA for the project associated with 22 main activities, the optimization models were solved by Lingo in two modes - with consideration of the secondary risks and without them. The characteristic values of risks and responses were also determined in the process.

Based on the results, considering secondary risks could increase the total cost of risks by 6,342 dollars, while neglecting secondary risks could result in selecting responses that cause more cost around 26,408 dollars. Failure to consider these secondary risks may result in much greater losses. Therefore, even though considering secondary risks may lead to increased costs, it is crucial to do so to avoid more potential losses. In this article, we also found that the optimal duration was 90 days based on the secondary risk, and by crashing it for 20 days, the cost of risks increased by about 3,570 dollars. Hence, it is safe to say that if we can increase the duration of the project until reaching the optimum time, we can reduce the costs related to the risk to some extent.

Despite the contributions of the present paper, there are some limitations. In this research, the dependence between risks and responses is not considered. Our model also does not consider the type of resource to respond to the risk; for example, the fuel reservoir is not a consumable resource and after the completion of the project can be used for future projects as well. Moreover, only the experts of the case company were interviewed to identify risks and responses. This may limit the generalizability of the study for other projects and industries.

Future research can expand our study by investigating more projects in oil and gas industry throughout the industry value chain such as onshore and offshore drilling projects, or refining projects. Moreover, future research should collect data on projects from other industries and employ other methods, such as the fuzzy theory, to compare the results with our findings. While the method used in this study was effective for a small-scale project, it may not be as effective for larger projects. As a result, it is recommended to consider other methods, like meta-heuristic methods, when tackling large-scale projects in different industries.

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