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An optimal model for Project Risk Response Portfolio Selection (P2RPS)

(Case study: Research institute of petroleum industry)

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Abstract

In the real world, risk and uncertainty are two natural properties in the implementation of Mega projects. Most projects fail to achieve the pre-determined objectives due to uncertainty. A linear integer programming optimization model was used in this work to solve a problem in order to choose the most appropriate risk responses for the project risks. A mathematical model, in which work structure breakdown, risk occurrences, risk reduction measures, and their effects are clearly related to each other, is proposed to evaluate and select the project risk responses. The model aims at optimization of defined criteria (objectives) of the project. Unlike similar previous studies, in this study, the relationship between risk responses during implementation has been considered. The model is capable of considering and optimizing different criteria in the objective function depending on the kind of project. In addition, a case study related to petroleum projects is presented, and the corresponding figures are analyzed.

Keywords

ε-constraint, Response synergism, Risk management, Risk responses.

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Introduction

In today's turbulent and ever-changing world, which is full of uncertainties and risks, knowledge and awareness are necessary for survival and success. A greater number of errors in management decision making and time and budget estimations are expected if the internal and external risk factors are not identified in a project. Risk factors are identified, controlled, or eliminated by risk management via selection and analysis of proper strategies. Risk is an uncertain condition that, if materialized will affect some work packages of the project in terms of quality, schedule, and cost (see, e.g., Ben-David & Raz, 2001; Seyedhoseini et al., 2009). Two substantial attributes of the risk event, the probability of occurrence and the negative impact (PMI, 2001), will be considered in this paper.

Risk management includes a set of necessary processes for identification, analysis, and reaction toward project risks aiming to maximize the results of desirable incidents and minimize the outcomes of undesirable incidents that may affect the major objectives of the project. The objective of risk management increases the possibility of project success by systematic identification and assessment of risks, presenting methods to avoid or reduce them, and maximizing opportunities (Chapman & Ward, 2003).

Risk management is one of the important fields of project management. All steps in risk management process are of equal importance. Incomplete implementation of each of the steps can lead to ineffective risk management (Conrow, 2003). On the other hand, many researchers have corroborated that risk assessment and analysis would not be effective without accountability (Hillson, 1999). Little information is available about the application of risk management in the real world though many results have been published in this regard (Lyons, 2002).

Risk management is, generally, referred to as project risk identification, awareness about the priority of each analysis, and assumption of an appropriate response strategy for these risks. Risk management includes risk identification, assessment, and response selection. Risk responses can be categorized by different methods. One categorization includes preventive and reactive responses.

Preventive/early response aims at avoiding the probability of risk occurrence. Reactive response also referred to as curing/ limiting/ precautious response, means to reduce the effect of risk occurrence. Preventive responses have also been preferred to reactive ones (Lyons, 2002). Two levels have been considered for classification of risk responses. The first level is the general categorization of the responses, which indicates the response risk, and the second level includes listing a set of specific responses under any strategy. Risk responses are classified into four categories including risk avoidance, reduction, transfer, and acceptance. Like threats, equivalent strategies can be defined for opportunities. In accordance with avoidance, reduction, transfer, and acceptance strategies in threats, benefit, sharing, enhancement, and acceptance strategies are defined for opportunities (Hillson, 2001).

Some frameworks have been developed for the selection of proper risk response strategies. Hillson (2001) defines the common practice in identification and selection of risk responses in the form of a cascade chart. In this method, risk avoidance strategy is checked first, and then transfer strategy will be studied if the risk could not be avoided. Reduction strategy will be studied if the response is not selected, and finally, risk acceptance strategy is investigated.

Previous studies have not focused on the interaction of risk responses and the synergistic effect of the responses, which is unavoidable in the real world. In the present study, risks are identified and the corresponding responses are selected on the basis of Work Breakdown Structure (WBS). Considering the effects of these responses on the project objectives and the results of synergism between the responses, the numbers of risk responses optimizing the objective function are selected from a portfolio of identified responses using a mathematical optimization model.

We developed a mathematical model to select the risk responses. Risk responses have not been considered individually. If the specific numbers of related response sets are selected, synergism (positive or negative) results will enhance the individual effect of each response. Different assessment criteria are considered in the objective function (e.g. time, cost, and quality) which attempts to select responses in order to maximize the amount of effects resulting from these criteria. If one criterion is considered, the problem will turn into a single objective mathematical model. Two or more assessment criteria will change the problem into a multi-objective mathematical model. In addition, different constraints have been considered to make a balance among the selected responses. These constraints attempt to consider requisites-prerequisites between risk responses.

In this context, the study begins with a literature review on risk management and project risk response selection methods. The study then will go on to present the proposed method in details. Then, we mainly explain how the proposed model works in reality at RIPI project. The result of the analysis is discussed and recommendation will be provided for managers and academician in the end.

The second part of this paper reviews the risk response related literature. The third part deals with developing a mathematical model based on the relationship between the risk responses. The fourth part consists of a case study in oil and gas industry followed by conclusions.

Literature review

Risk management was first introduced during the Renaissance period in the sixteenth century. Different models have been developed for project risk management in order to increase project success since 1990 (Boehm, 1991; Cooper et al., 2005). In most of these models, risk response is one of the basic steps. Some models have simple steps while others are more detailed. Different methods have been applied in project risk assessment in the past which have been covered in detail in publications dealing with risk management.

Fan et al. (2015) presented a programmed method to offer process risk responses based on Case-Based Reasoning (CRB). The method is consisted of five steps: (1) introduction of the corresponding problem and the related past problems, (2) recovery of the past cases by comparison of past and current risks, (3) measurement of similarities between the past and current cases, (4) review of applied risk responses analyzed in the previous cases and analysis of the relationship between the identified responses in the risks of the current project, and (5) providing a response which is compatible by assessment and choosing from the set of selected responses.

Fan et al. (2008) suggested a conceptual framework which describes the relation between risk responses and the project attributes (size, floating, and technical complexities). It further deals with a quantitative relation between the project parameters. Ultimately, an optimization analysis is offered for selection of response strategies for the current risks to minimize their implementation cost. López and Salmeron (2012), aiming on identification of software project risks affecting the performance of such projects, used a functional approach in the assessment of the risks identified, and finally, presented appropriate responses for management of these risks. Dikmen et al. (2008) proposed training based approach for risk management and applied this tool to an ongoing construction project because they believed that risk management was a task which had to be performed during the project’s life cycle. The case study proved that such tool could be employed for storage and updating of the data of project and ultimately the evaluations following the project. The major weak point of this tool is identification of risks and their ranking trend, as well as the reluctance of the employees for feeding the information concerning reasons for risks.

In another research performed in 2011, a Decision Support System (DSS) was developed for modeling and managing project risks and the relation between these risks in the project (Chao & Franck, 2011). The framework of this system is consisted of five phases: (1) identification of risk network, (2) assessment of risk network, (3) analysis of risk network, (4) risk response planning, and (5) risk control and monitoring. As mentioned, different methods have been reported in the literature pertaining to project risk management and the response planning phase in order to select proper response for each risk.

The approaches involved in the existing studies can be mainly classified into four categories: Zonal-based (ZB), Trade-off-based (TB), WBS-based (WBSB), and Optimization-model (OM) approaches. A summary of the related literature on project risk response strategy selection is shown in Table 1.

Table 1. Literature on project risk response selection

Authors	Focus of analysis	Approaches
Flanagan and Norman (1993)	The probability of occurrence and severity of the risks	ZB
Elkjaer and Felding (1999)	The degrees of influence and predictability of the risks	
Datta and Mukherjee (2001)	The weighted probability of immediate project risk and that of external project risk	
Piney (2002)	The acceptability of impact and likelihood of risks	
Miller and Lessard (2001)	The extent to which risks are controllable and the degree to which risks are special to the project	
Chapman and Ward (2003)	The expected costs of risk responses and their uncertainty factors	TB
Pipattanapiwong and Watanabe (2000)	The expected costs of risk after implementing the risk response and the degree of risk to access the risk response	
Kujawski (2002)	The probability of success for a given total project cost and the total project cost for a given probability of success	
Haimes (2005)	The costs of risk response and the percentage of work losses associated with it	
Klein (1993)	Uncertainties in project time, cost and quality	
Chapman (1979)	Work packages and risks and risk response activities associated with them	WBSB
Klein et al. (1994)	A variation on Chapman based on the analysis of a prototype activity	
Seyedhoseini et al. (2009)	Selecting a set of response strategies, which minimizes the undesirable deviation from achieving the project scope	
Ben-David and Raz (2001)	Project work contents, risks and risk actions and their effects	OM
Ben-David et al. (2002)	Interactions among work packages with respect to risks and risk abatement efforts	
Fan et al. (2008)	The risk-handling strategy and relevant project characteristics	
Kayis et al. (2007)	The available mitigation budget and strategic objectives of the project	
Zhang and Fan (2014)	Selecting a set of response actions, which maximizes the estimated risk response effects	

These approaches will be briefly described and elaborated.

Zonal-based (ZB) approach. A number of researchers have proposed the ZB approach for selection of risk responses. In this approach, a graph or a two dimensional matrix is used in order to identify the approximate area for selection of risk responses. Considering the determined criteria, these tools only specify the limits of risk responses, some of which will be indicated. Piney (2002) developed a programmed graph, which is extracted from the probability impact matrix based on the desirability of the decision maker for risk responses. Following the preparation of this graph, the response selection area is determined based on a specific procedure.

Elkjaer and Felding (1999) have used probability impact for selection of risk responses. The risk exposure area and its response are determined given the probability and impact of the risk. For example, for high probability and very effective risks, risk elimination strategy must be used. They introduced forecast-penetration matrix to determine risk responses.

Risk control and prediction capability criteria are used to determine risk responses in this matrix. Preventive programs are used for highly predictable, controllable risks and suggested strategies (including emergency programs, monitoring, and silence toward risks) are used in other parts. Some researchers have determined risk responses using risk classification matrices. Datta and Mukherjee (2001) developed one of these matrices, in which the risks are classified into external and internal types. In another matrix developed by Miller and Lessard (2001), the risks are classified into systematic and non-systematic types, and the capability of risk management is used for selection of risk responses. The limitation of this method is that only two criteria can be considered at a time (Zhang & Fan, 2014).

Trade-off-based (TB) approach. Some researchers have reported the application of TB approach or efficient frontier concept to evaluate risk responses. For example, Chapman and Ward (2003) investigated the relationship between the cost of response implementation and the cost of risk level. Based on this, the responses whose costs of implementation and risk level are worse than others are eliminated and the desirable choice is made from the efficient responses. Kujawski (2002) calculated the costs for response implementation and risk after performing the response using decision tree and drew the cumulative probability distribution curve.

Haimes (2005) calculated the efficient frontier in a project for fighting plant pests using exchange of response and risk costs following the response. Klein (1993) developed a conceptual model based on the diagram for interfacial penetration of objective-related uncertainty. The efficient frontier for response forms considering time, cost, and quality and the desirable choice is made using the trade-off between these criteria. The limitations of this method include consideration of only two factors and that the results are based on qualitative analysis (Zhang & Fan, 2014).

WBS-based (WBSB) approach. Some researchers have used the work breakdown structure (WBS) approach to establish a relationship between the risk response assessment method and other project management systems. The first work carried out in by Chapman (1979), developed a methodology referred to as Synergistic Contingency Evaluation and Response Technique (SCERT), in which the individual components of WBS are investigated, and the risks and corresponding responses are identified. The method requires a great deal of studies in big projects.

To reduce this difficulty, Klein et al. (1994) developed the modified version of this model, where template activities are investigated for each activity instead of risks and responses, and the results are extended to all activities of the template activity set. Template activity represents a set of similar activities. In other words, a template activity is defined if all the project activities are almost similar. There is no guarantee that the obtained responses for the risk response selection problem are optimized in this approach (Zhang & Fan, 2014).

Optimization-model (OM) approach. The risk response selection problem can be modeled in the format of an optimization problem. The objective function is minimization of the costs of risk response implementation and its constraints including combination of strategies (Zhang & Fan, 2014). In this approach, a set of responses are selected such that the corresponding objective function is optimized, and the system limitations are complied. The optimization model must calculate an optimum solution in order to minimize the total costs of risks and response implementation.

Using the total cost minimization approach, Ben-David and Raz (2001) developed a general framework and a heuristic algorithm for selection of a set of responses. The corresponding mathematical model developed by Ben-David et al. (2002) for the project functional elements correlates risk occurrences effective on the functional elements and the set of risk reduction responses. The effects of risk events are based on financial loss. The objective function is aimed at minimizing the total expected risk costs, which is consisted of risk reduction costs and the expected risk costs related losses. Seyedhoseini et al. (2009) proposed a project risk response model based on decision support system design. This model is closely related with project planning system, and includes project evaluation, ranking, and risk assessment, response evaluation, and response ranking subsystems.

Statement of the problem

According to the literature review, a mathematical model is developed here for selection of project risk responses. Different risks are considered for the project activities and different responses are selected for each risk. In addition, risk responses have not been considered individually but are correlated. The selection of related responses can affect their influence on the project objectives. These effects can appear as positive or negative synergisms. If the specific numbers of related response sets are selected, the synergism (positive or negative) results will enhance the individual effect of each response.

Different assessment criteria are considered in the objective function which attempts to select responses for maximizing the amount of effects resulting from these criteria. If one criterion is considered, the problem will turn into a single objective mathematical model. Two or more assessment criteria will change the problem into a multi-objective mathematical model. In addition to the interaction between responses, different constraints are considered to create a balance among the selected responses. These constraints attempt to consider requisites-prerequisites between the risk responses and further prevent the selection of antithetic responses.

In this study, using the OB approach for selection of risk responses, first, a conceptual model for evaluation and selection of project risk responses is proposed, which clearly relates WBS, risk events, risk reduction actions, and their effects. It is necessary to consider the WBS as the relationship basis in order to establish a relationship between the risk response selection models and general project management system. The relationship is such that if a specific number of responses are selected, a positive or negative synergism will be activated between the responses. In other words, the WBS is an important basis in integration of a comprehensive project management system with other subsystems such as risk management.

In the proposed model, it is attempted to select a set of responses such that the objective function is optimized in addition to meeting the system constraints (budget, technical dependences of responses, etc.). The objective is maximizing the expected desirable effects resulting from the risk responses (i=1, 2,…, m) on a number of desirable project objective criteria (L=1, 2,..., l). The working elements are the same as the components of WBS and are represented as K=1, 2,…, k, and the risks are represented by j=1, 2, …, n. Risk responses interact with each other, and the risks are assumed to be independent. Risk events may negatively or positively affect one or more work activities. The relationship between risk events and responses and their effects on the project objectives are shown in Figure 1.

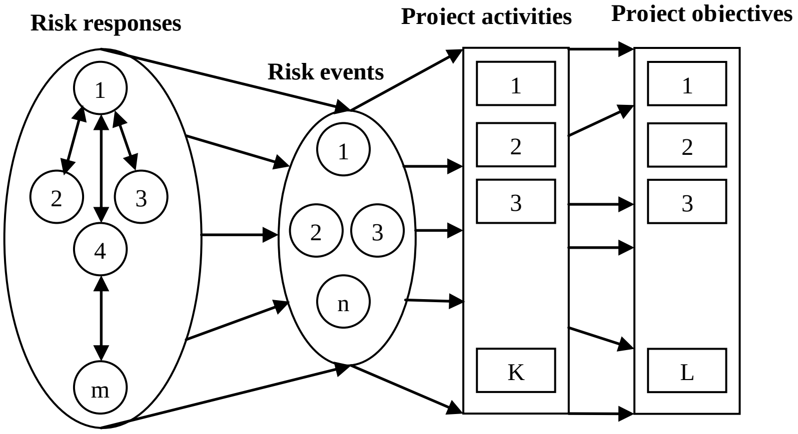

Fig. 1. Proposed framework for selection of project risk responses considering the relationship between responses

The mathematical method developed in this paper intends to select proper responses for project risks. It is a multi-objective and Binary Integer Programming (BIP). The objective is maximizing the desirable effects of criteria in the projects. Sets, parameters, and variables are defined as follows:

Sets

Risk responses	$i = 1,...,m$
Risks	$j = 1,...,n$
Activities	$k = 1,...,l$
Assessment criteria (project objectives)	$l = 1,...,L$

Parameters

The Set of responses related to risk j. Its selection and implementation cause synergism of their effect on the jth risk.	B_j
The set of all pairs of strategies that exclude each other.	$\overleftrightarrow{\mathrm{M}}$
The set of all pairs of strategies that cooperate with each other.	$\bar{\mathrm{M}}$
Cost required for implementation of the ith risk response	c_i
Variation in time of activity k if risk j occurs.	s_j^k
Improvement in the time of activity k if the ith risk response is implemented to control the jth risk.	$\tilde{s}_{ij}^k$
Variation in time of activity k resulting from the synergism of risk responses related to the jth risk	$\tilde{s}a_j^k$
Maximum allowable delay for activity k	ε_k
The quality of activity k affected by risk j	q_j^k
The quality of activity k changed if the ith risk response is implemented to control the jth risk	$\tilde{q}_{ij}^k$
The quality of activity k changed resulting from the synergism of implementation of risk responses related to the jth risk	$\tilde{q}a_j^k$
Maximum allowable quality reduction for activity k	δ_k
Maximum project time	T_{max}
Maximum project quality	Q_{max}
Effect of the ith risk response effective on the jth risk for the kth activity on the lth criterion	Atr_{ij}^{lk}

Synergism resulting from the risk responses related to the j^th^ risk for the k^th^ activity on the l^th^ criterion	g_j^{lk}
Minimum risk responses selected for synergism for the j^th^ risk	m_j
Maximum risk responses selected for synergism for the j^th^ risk	M_j

Variables

If the i^th^ risk response is selected for the j^th^ risk, it is 1, otherwise zero.	x_{ij}
If synergism for the j^th^ risk occurs, it is 1, otherwise zero.	LM_j

Considering the parameters and variables of the problem, the Binary Integer Programming (BLP) model of this work is presented as follows:

$$max\, z = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{K} Atr_{ij}^{lk} x_{ij} + \sum_{j=1}^{n}\sum_{k=1}^{K} g_j^{lk} LM_j \qquad l = 1, \dots, L \qquad (1)$$

$$\sum_{i=1}^{m} C_i\, max_j(x_{ij}) \leq B \qquad (2)$$

$$\sum_{j=1}^{n} S_j^k - \left(\sum_{j=1}^{n}\sum_{i=1}^{m} \tilde{s}_{ij}^k x_{ij} + \sum_{j=1}^{n} sa_j^k\, LM_j\right) \leq \varepsilon_k \qquad k = 1, \dots, K \qquad (3)$$

$$\sum_{j=1}^{n} q_j^k - \left(\sum_{j=1}^{n}\sum_{i=1}^{m} \tilde{q}_{ij}^k x_{ij} + \sum_{j=1}^{n} qa_j^k\, LM_j\right) \leq \delta_k \qquad k = 1, \dots, K \qquad (4)$$

$$\sum_{j=1}^{n} S_j^k - \left(\sum_{j=1}^{n}\sum_{i=1}^{m} \tilde{s}_{ij}^k x_{ij} + \sum_{j=1}^{n} sa_j^k\, LM_j\right) \leq T_{max} \qquad k = K \qquad (5)$$

$$\sum_{j=1}^{n} q_j^k - \left(\sum_{j=1}^{n}\sum_{i=1}^{m} \tilde{q}_{ij}^k x_{ij} + \sum_{j=1}^{n} qa_j^k\, LM_j\right) \leq Q_{max} \qquad k = K \qquad (6)$$

$$\sum_{i \in B_i} x_{ij} - m_j + 1 \leq M * LM_j^m \leq \sum_{i \in B_i} x_{ij} - m_j + M \qquad j = 1, \dots, n \qquad (7)$$

$$M_j - \sum_{i \in B_i} x_{ij} + 1 \leq M * LM_j^M \leq M_j - \sum_{i \in B_i} x_{ij} + M \qquad j = 1, \dots, n \qquad (8)$$

$$LM_j^M * LM_j^m = LM_j \qquad (9)$$

$$x_{ij} + x_{i'j'} \leq 1 \qquad (A_i, A_{i'}) \in \overleftrightarrow{M} \qquad i, i' = 1, \dots, m \quad j, j' = 1, \dots, n \qquad (10)$$

$$x_{ij} + x_{i'j'} = 1 \qquad (A_i, A_{i'}) \in \overleftrightarrow{M} \qquad i, i' = 1, \dots, m \quad j, j' = 1, \dots, n \qquad (11)$$

$$x_{ij} - x_{i'j'} \leq 0 \qquad (A_i, A_{i'}) \in \bar{M} \qquad i, i' = 1, \dots, m \quad j, j' = 1, \dots, n \qquad (12)$$

$$x_{ij}, x_{i'j'}, LM_j, LM_j^m, LM_j^M \in \{0,1\} \qquad i, i' = 1, \dots, m, \quad j, j' = 1, \dots, n \qquad (13)$$

In this model, the objective function aims at optimizing the quantity obtained from each assessment criterion including the sum of effects resulting from the selection of each risk response in that criterion as well as the sum of effects of synergism for each risk.

Constraint 2 states that the cost of implementation of risk responses must be less than the allocated budget.

According to constraint 3, risk responses must be selected such that the difference in improvement in time of the kth activity and the effect of risk on its time must be less than the expected value.

Constraint 4 states that risk responses must be selected such that the difference in improvement in time of the kth activity and the effects of risk on quality of kth activity must be less than the expected value.

According to constraint 5, the last activity of the project must end at the end of the expected time (T_{max}).

Constraint 6 says that the last activity of the project must fulfill the quality expected (Q_{max}).

According to constraints 7-9, if a known number of risk responses are selected for the corresponding risk, the resulting synergism will increase or decrease the effect of that risk. Constraint 7 implies that if the number of responses selected is greater than mj, LM_j^m will be one, and otherwise zero. In addition, according to constraint 8, if the number of responses selected is less than Mj, LM_j^m will be one, and otherwise zero. Constraint 9 states that if the number of responses selected is within the desirable range, synergism will be activated and LM will be equal to 1, and otherwise zero.

Constraints 10-12 are known as balance constraints. Constraint 10 states that strategies A_i and $A_{i'}$ exclude each other. Constraint 11 ensures that one strategy must be selected in the case of strategy exclusion. Constraint 12 says that the selection of one strategy requires that another specific strategy be selected too.

Constraint 13 is a binary mode indicator, too.

Case study

In the present work, the model developed in “Design, Construction, and Commissioning of Pilot Plant for Delayed Coking Process" project in the Research Institute of Petroleum Industry (RIPI) in Iran was used and its validation was tested. There are 6 activities, 4 risks, and 10 risk responses in the project. In addition, three criteria; namely cost, quality, and time were considered and these objectives were planned to be optimized. Tables 2-4 show the project activities, risks, and risk responses.

Table 2. Project activities based on WBS

Activity	Description
1	Conceptual design of the pilot plant
2	Basic design of the pilot plant
3	Detailed design of the pilot plant
4	Monitoring the procurement, construction and installation of the pilot plant
5	Pre-commissioning and commissioning of the pilot plant
6	Solving the potential problems and preparation of the report

Table 3. Description of identified project risks

Risk	Risk description
1	Providing misinformation on design by the contractor
2	Disorder in providing the financial resources
3	Incompatibility of the received equipment with the approved engineering documents
4	Inadequate human resource expertise

Sets B1, B2, and B3 show the response sets, which may lead to synergism in the response effects on cost, quality, and time criteria, if selected simultaneously.

Table 4. Description of risk responses in the project studied

Response	Description
A1	Review of timing for procurement of the main equipment based on planning
A2	Careful control of the design documents
A3	Planning and holding training courses for contractors and employees
A4	Signing contracts with consultation companies for modification of the equipment design
A5	Review of paying system
A6	Preparation of a comprehensive data bank for suppliers and contractors
A7	Substitution of some imported equipment with similar domestic ones
A8	Development and implementation of the management selection system
A9	Design and application of cost evaluation and budgeting
A10	Application of contingency reserves (unallocated funds)

Maximum time and quality in the last project activity is 10. The costs required for implementation of risk responses are shown in Table 5. The total available budget for implementation of risk responses is 700 million Rials. Time delays for each activity as a result of a risk are shown in Table 6. The qualitative reduction of each activity as a result of a risk event can be determined based on the experts' and project managers' comments. The time effects of each risk response on the time activity by affecting each risk are shown in Table 7. The qualitative effect of each risk on the quality of each activity by affecting each risk can be determined.

Table 5. Expenses required for implementation of risk responses

Response	Implementation cost (10,000 Rials)
1	15,000
2	10,000
3	10,000
4	12,000
5	10,000
6	12,000
7	13,000
8	15,000
9	10,000
10	12,000

Table 6. Time delays for each activity as a result of a risk

S_j^k	Activity					
	1	**2**	**3**	**4**	**5**	**6**
1	2	1	1	1	2	1
2	1	2	0	1	2	0
3	1	3	1	0	0	0
4	1	4	1	2	0	2

Table 7. The time effect of each risk response on the activity time by affecting each risk

$\tilde{s}_{ij}^k$		Risk response									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Activity 1	1	0.1		0.1		0.2	0.1		0.1	0.1	0.1
	2		0.1	0.1		0.1		0.1	0.1	0.1	
	3		0.1	0.1	0.1		0.1	0.1			0.1
	4		0.1	0.1	0.1				0.1	0.1	0.1
Activity 2	1										
	2										
	3	0.1	0.1		0.1	0.1		0.2	0.1	0.1	
	4		0.1	0.1			0.1		0.1		

Continue Table 7. The time effect of each risk response on the activity time by affecting each risk

$\tilde{s}_{ij}^{k}$		**Risk response**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Activity 3	1	0.2	0.1		0.2	0.2	0.1	0.1		0.2	0.1
	2										
	3			0.2		0.1			0.1		
	4										
Activity 4	1		0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
	2	0.1		0.1		0.1				0.2	
	3										
	4				0.1		0.2				0.1
Activity 5	1	0.1		0.1	0.1		0.1	0.1		0.1	
	2		0.1				0.1				
	3										
	4										
Activity 6	1	0.2	0.1	0.1		0.2		0.1	0.2		0.1
	2										
	3										
	4		0.1				0.1				0.1

The time effects resulting from synergism of risk responses related to each risk on each activity time are shown in Table 8. Similarly, the qualitative and financial effects due to synergism of risk responses related to each risk on the quality and cost of each activity can be determined. Maximum allowable reduction times and qualities for each activity are shown in Table 9.

The effect of each risk response on each risk for different project activities on the time, quality, and cost criteria were similarly determined and used in the model based on the experts' and project managers' comments. Minimum and maximum risk responses, which must be selected to activate the corresponding synergisms, are given in Table 10.

Table 8. Time effects resulting from synergism of risk responses related to each risk on each activity time

	Risk	**Activity**					
		1	**2**	**3**	**4**	**5**	**6**
g_j^{lk} Time	1	0.01		0.01		0.02	0.01
	2	0.01	0.02		0.01		0.01
	3			0.02		0.01	
	4	0.01			0.02		

Table 9. Maximum allowable reduction times and qualities for each activity

	Activity					
	1	**2**	**3**	**4**	**5**	**6**
δ_k	10	10	10	10	10	0
ε_k	10	12	15	10	8	0

Table 10. Minimum and maximum risk responses in synergistic sets

Range	**Response synergistic set (B_j)**		
	1	**2**	**3**
m_j	2	2	2
M_j	5	4	3

The following constraints are related to the requisite and prerequisite constraints for implementation of risk responses for each risk. The first constraint states that between response 10 for the third risk and response 7 for the second risk, one should be selected. According to the next constraint, between response 9 for the fourth risk and response 3 for the first risk, one should be selected. The third constraint says that if response 1 is selected for the second risk, response 5 must definitely be selected for the third risk:

$$X_{7,2} + X_{10,3} \leq 1$$

$$X_{3,1} + X_{9,4} \leq 1$$

$$X_{1,2} - X_{5,3} \leq 1$$

Considering that the corresponding criteria are time, quality, and cost, the problem is a multi-objective model. Therefore, ε-constraint method was used to solve this problem using LINGO software.

ε-constraint method

This method is based on the conversion of a multi-objective problem to a single objective one such that only one objective is optimized while the other objectives are considered as constraints. In fact, this method is one of the known approaches for multi-objective problems that solves the problem by transferring all the objective functions, except for one, to a constraint in each step and obtains Pareto frontier (Mavrotas, 2009). This method offers a desirable number of Pareto points through balancing of the objective functions. The steps in ε-constraint method are as follows:

$$\begin{aligned} &\min f_1(t) \\ &f_2(t) \leq \varepsilon_2 \\ &f_n(t) \leq \varepsilon_n \end{aligned} \qquad (14)$$

1. One of the objective functions is chosen as the main objective function while the other objective functions are considered as constraints in the model.
2. The problem is solved as a single objective each time considering one of the objective functions. The best and worst values are obtained for each of the objective functions.
3. The interval between the two optimal values (the best and worst values of the objective functions) is divided into predetermined numbers (cut-offs) and a table is prepared for 2,…, n values.
4. The problem is solved with the main objective function using 2,…, n values each time, and the Pareto responses obtained are ultimately reported.

Computational results

Based on ε-constraint method, quality and cost criteria are considered as ε-constraints. For each function, there are 5 cut-offs (r_j= 0.2, 0.4, 0.6, 0.8, and 1), and thus the total number of answers is 25. In addition, the problems are solved in three states with the budget limitations of 70,000, 100,000, and 50,000. The non-dominant answers obtained by this algorithm are shown in Table 11. As shown, the number of non-dominant answers is 3, 4, and 5 for the first, second, and third states, respectively. On the other hand, it is better to have more criteria because risk responses are planned to be selected such that more time and quality are preserved against the risks. Minimum and maximum objective functions are shown in Table 12. The epsilon values in each iteration are obtained using formula 15:

$$\varepsilon_i = maxf_i - (maxf_i - minf_i) \times r_j \qquad i = 1,2 \qquad j = 1, \dots ,5 \qquad (15)$$

As clearly observed, decreasing budget decreases the objective functions. Objective functions are directly proportional to the budget. The budget is reduced from 100,000 to 50,000, and thus each of the objective functions are reduced accordingly.

As shown in Table 13, there are fewer selected responses with reduced budget. When this happens, the model selects such responses as to activate the synergism of the sets to increase the effect of responses on the objective functions.

Moreover, as the responses of budgets of 100,000 and 50,000 are clear, they have not been selected in the synergistic responses of the third set. On the other hand, Pareto solutions have been arranged in Table 11 in decreasing order with respect to time reduction and increasing order with respect to increased costs. Thus, it can be concluded that the selection of responses of the third set has decreased the time and increased the costs. However, if responses of the third set are not selected, the costs will be decreased while the time increases.

Table 11. Non-dominant responses

Budget	Number	Time	Quality	Cost	Cut-off 1	Cut-off 2
100,000	1	8.1	76.8	2100	0	0.2
	2	8.1	77	2015	0	0.4
	3	8	79	2205	0.3	0.2
	4	7.96	81.8	2275	0.3	0.4
70,000	1	6.33	60.4	1505	0	0.4
	2	6.01	59.9	1990	0.3	0
	3	6.06	64	1925	0.3	0.2
50,000	1	4.35	41.1	960	0	0.4
	2	4.15	42.1	1240	0.9	0.2
	3	3.98	42.5	1265	0.9	0.6
	4	3.88	42.5	1375	0.3	0.2
	5	3.66	38.8	1465	0.3	0

Table 12. Maximum and minimum objective functions

Budget	100,000		70,000		50,000	
Objective	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Time	0	8.1	0	6.33	0	4.35
Quality	0	79.8	0	64	0	42.5
Cost	0	2500	0	1990	0	1465

Table 13. Responses selected for non-dominant responses

Number	Non-selected responses	Number of non-selected responses	B1 response set	B2 response set	B3 response set
1	4,7	2	▨	▨	
2	1,4	2	▨	▨	
3	4,9	2	▨	▨	
4	4,9	2	▨	▨	▨
1	1,4,7,9	4	▨	▨	
2	6,7,8,9	4	▨	▨	▨
3	4,6,7,9	4	▨	▨	▨
1	1,3,4,7,8,9	6	▨	▨	
2	3,4,6,7,8,9	6	▨	▨	
3	3,4,6,8,9,10	6	▨	▨	▨
4	2,3,4,6,8,9	6	▨	▨	▨
5	2,3,6,8,9,10	6	▨	▨	▨

Table 14 shows the selected responses for each risk, and Figure 2 indicates the number of selected responses for each risk in all three problems and for Pareto answers. As clearly indicated in the trend and tilt of lines in Figure 2, decreasing budget reduces the number of selected responses. By decreasing the budget, the number of selected responses in all Pareto answers decreases. On the other hand, increase or decrease of the number of risk responses directly affects all of the three objective functions while decreasing the number of risk responses has the reverse effect. However, if the number of selected risk responses is fixed and only the type of risk responses changes, the objective functions will be affected differently. This means that the selection of a set of responses causes optimization of one objective function such as project time while the selection of another response set causes optimization of another objective function.

Table 14. Number of selected responses for each risk in the non-dominant responses found

Number	Risk 1	Risk 2	Risk 3	Risk 4
1	8	8	8	6
2	8	8	8	7
3	8	8	8	7
4	8	8	7	7
1	6	6	6	6
2	6	6	6	5
3	6	6	6	5
1	4	4	4	4
2	4	4	4	3
3	4	4	4	3
4	4	4	4	3
5	4	4	4	3

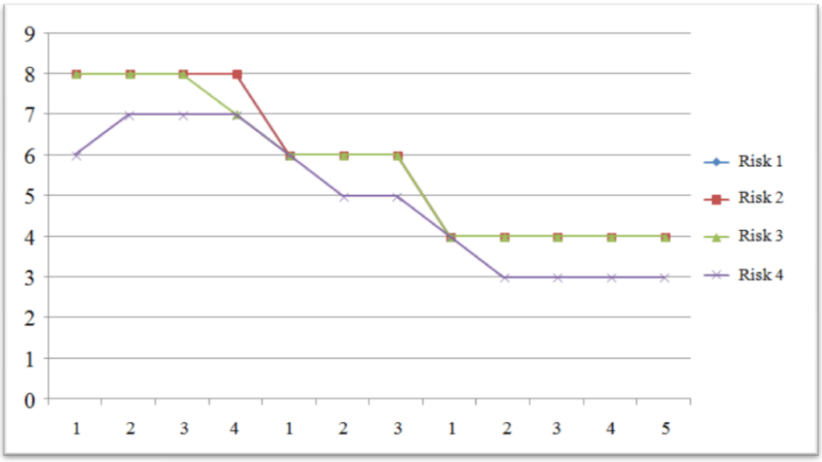

Fig. 2. Effect of number of selected responses on cost

Table 15 shows the selected responses on the first Pareto answer of the problem with a budget of 50,000. As observed, response strategies 2, 5, 6, and 10 have been selected for all risks. Fewer risk responses have been selected in the model because of the budget constraints. Thus, the four risk responses, which greatly affect most of the risk effects, have been selected.

Table 15. Selected risk response strategies for each risk with the budget of 50000

Response strategy	Risk 1	Risk 2	Risk 3	Risk 4
1				
2	√	√	√	√
3				
4				
5	√	√	√	√
6	√	√	√	√
7				
8				
9				
10	√	√	√	√

Discussion and Conclusion

A linear integer programming optimization model was developed in this work for selection of risk responses of a project. The model attempts to find proper responses for different risks. The answers will be based on optimization of the criteria considered in the objective function. The objective function is capable of including and optimizing different desirable criteria. Time and quality constrains as well as the relationship between different responses in this model were considered. The relationship is such that if a specific number of responses are selected, a positive or negative synergism will be activated between the responses. Constraints pertaining to prerequisites, requisites, and balance of selected responses were also taken into account.

To solve the model, a case study regarding a petroleum project including project cost, time, and quality criteria as the objective functions was considered. ε-constraint method, coded in LINGO software, was used to solve the model. Having solved the model in one state with different budgets, Pareto responses 4, 3, and 5 were found for the first, second, and the last states, respectively. The results showed that budget reduction simultaneously decreases all of the three objective functions.

Finally, Pareto answers obtained were analyzed and the results revealed that this model enables the project managers to predict proper responses to improve the effects of risks of projects. Fuzzy theory can be used in the model to reduce errors of experts. Meanwhile, in order to analyze project objectives, the model can be similarly used to prioritize activities based on the work break sheet (WBS), focusing on management of these activity risks. Clustering and assessing important factors of risk through polling experts and available mathematic models is suggested for future studies. This means that suitable clustering by mathematical planning models and network concepts must be presented in addition to risk assessment in order to achieve more valid analytical results.

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