A Novel Fuzzy Expert System for Project Portfolio Risk Management: Case Study of a Construction Company

Sayyid Ali Banihashemi [1] and Mohammad Khalilzadeh[2]*

[1] Department of Industrial Engineering, Payame Noor University, Tehran, Iran.
E-Mail: banihashemi@pnu.ac.ir
[2] CENTRUM Católica Graduate Business School, Pontificia Universidad Católica del Perú, Lima, Peru.
*Corresponding Author. E-Mail: khalilzadeh@pucp.edu.pe

ABSTRACT

Executive managers of organizations are seeking for solutions to complete projects within the predetermined duration, budget and quality. Obviously, improper risk management processes are the main reasons for the failure of projects. This research aims to design a new fuzzy expert system for project portfolio risk management. In this paper, the main risk factors of the project portfolio are identified through library research and expert judgment. Then, the decision-making trial and evaluation laboratory (DEMATEL) method is used to identify the causal relationships among risk factors. Subsequently, the combination of Fuzzy-analytic Hierarchy Process (F-AHP) and Failure Mode and Effects Analysis (FMEA) methods is exploited to determine the most important risk factors. The results show that the risk of laws, regulations and warranties, the risk of procurement and distribution costs and the risk of information system failure occupy the first to third ranks in the study project, respectively. In the following step, different risk response strategies are proposed to tackle the major risk factors. Finally, a fuzzy multi-objective mathematical programming model is developed to select the optimal risk response strategies considering the three main objectives of time, cost and quality. The findings showed that the proposed fuzzy expert system has the capability and efficiency for identifying and assessing the risks of the project portfolio and selecting the optimal risk response strategies in the case study.

KEYWORDS: Project portfolio, Risk management, DEMATEL, Fuzzy AHP-FMEA, Multi-objective optimization.

INTRODUCTION

Risk is considered as a condition that is beyond the control of the project team and if it occurs, it will have a direct impact on the project. In other words, risks are potential problems in a project that are likely to occur in the future. Accordingly, project managers seek to take action if problems arise or alternatively try to avoid them before they occur, while many problems will occur ahead of time (Khalilzadeh et al., 2020). This is where the concept of project risk management comes into play. Risk management is one of the most critical components of projects, so that poor management and forecasting in this regard may lead to failure of projects. Risk identification and assessment together with the allocation of required resources and time to risk response strategies are among the fundamental tasks of project managers. Indeed, risk management involves the process of identifying, evaluating, managing and controlling project risks (PMBOK, 2017). Project risks may also affect the environment of the performing organizations and make them vulnerable, which may be more critical for larger and more complex projects.

Project portfolio is a set of projects, plans or other tasks that have been put together to facilitate their effective management and achieve the strategic goals of the business (Ismah Hashim and Chileshe, 2012). Moreover; projects or programs of a portfolio are not necessarily interrelated (PMBOK, 2017). In addition, the projects and programs inside a portfolio can be evaluated, ranked and prioritized. The organization may

Received on 31/10/2021.
Accepted for Publication on 24/4/2022.

have more than one project portfolio, each of which is specific to a particular business goal. The project portfolio should reflect the decision, guidance and progress of the organization. We always face risks and uncertainties in organizations, where managing and controlling them poorly will cause significant losses and have great impacts on the quality, cost and duration of projects. Moreover, risks are involved in every business and many project management issues arise from risk-related uncertainties. Together with the increasing number of complex and large projects, their risks have been increasing in terms of number and impact, so that organizations urgently need to follow up risk management processes to protect themselves from the consequences and impacts of risks (such as technical, financial, … etc.). On the other hand, most projects are implemented in project-oriented organizations inside the project portfolios. Therefore, the appropriate use of project portfolio management in project-based organizations leads the organization to gain benefits that it is not possible to obtain through each project separately. Risk management is one of the most important elements of project portfolio management that enables the organization to gain the necessary awareness of the opportunities and threats of the environment. Therefore, understanding risk management at the project portfolio level and its effectiveness on the success of the project portfolio is vital for such organizations to succeed.

Further, to the authors' knowledge, the review of previous studies on project portfolio risk management shows that there has not been an appropriate and practical fuzzy expert system for project portfolio risk management. However, the application of such a system is substantial for any project-based organization. As a result, the current study presents a novel fuzzy expert system for project portfolio risk management considering a real case study of a construction company in Iran to evaluate the efficiency and effectiveness of the proposed integrated model, in which the developed DEMATEL method is used to identify the causal relationships among main risk factors in the project portfolio. Also, the AHP and fuzzy FMEA methods are exploited to evaluate major risk factors and finally, a fuzzy multi-objective mathematical programming model is developed to find the optimal risk response strategies.

LITERATURE REVIEW

Risk management as one of the fundamental pillars of project management is considered as a key managerial challenge at the organization level (Olfat et al., 2010). Construction projects have the highest level of risk and uncertainty due to their characteristics (Esmaeilzadeh, 2011). The greater the focus on risk management in the early stages of the project, the less deviation from the baseline during the implementation phase. Risk management focuses specifically on the components of the project iron triangle (cost, time and quality). According to project risk management, risks must be identified and assessed and response strategies must be developed for risks that have high likelihood and/or consequence to be implemented at the time of risk occurrence (PMBOK, 2017; Khaksari et al., 2009). One of the most important steps in risk management is developing risk response strategies. Any action taken to respond to an identified risk can eliminate or reduce its likelihood and/or impact (Mokhtari and Hasanzadeh, 2019; PMBOK, 2017).

Project portfolio management has two different groups of processes: selecting and planning the right projects and executing those projects correctly. One of the well-known criteria considered for project selection is risk. Identifying risks, evaluating their effects and planning appropriate responses are the three primary processes in project risk management (Rabbani et al., 2010). Numerous decision-making methods and models have been presented to prioritize and select risk response strategies. The aim of these models is to select a set of responses that have the greatest impacts on reducing the level of project risks due to the limited available resources (Zhang and Guan, 2018). Since most projects are implemented by project-based organizations within project portfolios, the knowledge of risk management at the project portfolio level and how it affects the success of the project portfolio is extremely important and vital for organizations. Therefore, designing an expert system for identifying and evaluating risks as well as responding to risks in order to maximize the profitability of the project portfolio and reduce costs is an urgent need for project-based organizations. In the present study, a novel expert system, which is a combination of identifying different types of risks at the project portfolio level, evaluating the likelihood and impact level of each of the identified risks and finally developing a mathematical programming model to respond to major risks at the project portfolio, is proposed. In addition, the fuzzy set theory is exploited to better deal with ambiguity and vagueness of data in real-world conditions.

Lee et al. (2009) proposed a schema for managing the risks of large-scale engineering projects using the Bayesian belief network and implemented it in the Korean shipbuilding industry. Polak et al. (2010) evaluated risk management strategies using the minimum-maximum project portfolio optimization method. A minimax model was developed and the parametric analysis of the risk threshold was performed. Gampert and Modlener (2011) evaluated the threats and opportunities of electrical project portfolio contracts with an European management approach. They examined the challenges that need to be overcome to build an electricity contract across Europe. Baguti and Ghosh (2011) examined the risks involved in Build-Operate-Transfer (BOT) projects. Ben et al. (2012) proposed a bacterial nutrition-based approach for portfolio optimization problem. They designed an optimization model by introducing internal and external liquidity risk and developing relevant indicators to measure liquidity risk/external environment. In addition, Hwee and Poon (2013) performed risk analysis in dam construction in Malaysia.

Poursadegh et al. (2013) implemented a model of risk management, based on the theory of evolutionary games with the approach of military organizations. They simultaneously presented a model in military risk management by presenting an exploratory-inferential model. Hemmati and Rasoulpour (2014) presented a combined algorithm of fuzzy failure point analysis and class weighted technique to identify and prioritize project risks in a gas supply project. Teller and Kock (2013) examined how portfolios' risk management can affect project success. The study provided evidence that portfolio risk identification, operational risk management process recognition and risk management culture directly affect risk transparency, while risk prevention, risk monitoring and integration of risk management in the project are directly related to risk capacity. Ghorbel and Trabelsi (2014) studied the risk management of energy project portfolio and over-value of time change using paired methods. This work was related to the statistical modeling of the structure of dependence between three energy markets: crude oil, natural gas and heat oil, using value-at- risk estimation method.

Bagherian (2015) developed a project portfolio risk management methodology based on the project portfolio risk management standard. Mensi et al. (2015) evaluated the relationship between different variables of the main cross-border oil market with major future markets, such as oil, gold, silver, wheat, corn and rice and the consequences of project portfolio risk management in Saudi Arabia. They considered the two-dimensional model of Dynamic Conditional Correlation Fractionally Integrated Asymmetric Power ARCH (DCC-FIAPARCH) with and without structural gaps. Zamani et al. (2017) studied the framework of applying risk management in fuzzy environment in implementation engineering value of construction projects in Khorramshahr port. This research sought to provide an integrated framework of value engineering and risk management. Onyiriu (2016) evaluated project portfolio structure and risk management in developing economies in banks. Charwand et al. (2017) studied the project portfolio risk management for electricity retailers based on a minimum risk preference. For doing so, they examined the decision making about the uncertainty of the electricity retailer in order to maximize the total expectation using simulations by the ARIMA model. Mujalli (2018) investigated the risk of road accidents. He identified the main factors influencing road accidents according to their severity using Bayesian networks.

Fattahi and Khalilzadeh (2018) evaluated risk using a new integrated model consisting of fuzzy FMEA, developed Multi-Moora (Multi-Objective Optimization on the basis of Ratio Analysis) and AHP methods under fuzzy environment in Kerman Steel Industries factory in Iran. In this study, two criteria of mean fuzzy weight risk rating and modified fuzzy weight risk rating were used. Karmakar and Poul (2019) evaluated the project portfolio risk management using VaR (Compare Value-at-Risk) and CVaR (Conditional Value-at-Risk) methods. They proposed predictive approaches and marginal models for the individual return series and a common model for dependencies between paired series. Khalilzadeh et al. (2020) proposed a hybrid FMEA-VIKOR (VlseKriterijuska Optimizacija I Komoromisno Resenje) approach for Health and Safety Executive

(HSE) risk assessment. Nabizadeh et al. (2021) applied the FMEA and fuzzy VIKOR methods for identifying and assessing health, safety and environment risks. Khalilzadeh et al. (2021) identified the main risk factors of oil and gas construction projects through historical document analysis and expert judgment method. Then, the interrelationships among risk factors were determined and ranked using the DEMATEL-ANP (Analytic Network Process) method.

Table 1. Summary of related studies

Study	**Year**	**Uncertainty**		**Decision-making Method**						**Deterministic approach**	**Heuristic/Metaheuristic approach**	**Multi-objective mathematical model**
		Probabilistic	**Fuzzy**	**ANP**	**FMEA**	**DEMATEL**	**AHP**	**MOORA**	**TOPSIS**			
Poursadegh et al.	2013	*										
Hemmati & Rasoulpoor	2014				*						*	*
Bagherian	2015									*		
Zamani et al.	2007									*		
Lee et al.	2009	*										
Polak et al.	2010	*								*		
Gampert & Madlener	2011											
Ben et al.	2012										*	*
Teller & Kock	2013											
Ghorbel & Trabelsi	2014											
Mensi et al.	2015									*		*
Onyiriu	2016									*		
Charwand et al.	2017	*								*		
Fattahi & Khalilzadeh	2018				*		*	*				
Karmakar & Paul	2019									*		
Khalilzadeh et al.	2020		*	*								
Khalilzadeh et al.	2021		*	*		*						
Nabizadeh et al.	2021		*		*							
This study	**2021**		*		*	*	*			*		*
Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)												

The projects or programs of a portfolio are not necessarily related to each other. Previous studies on project portfolio risk management show that there has not been a comprehensive fuzzy expert system for project portfolio risk management including identifying and assessing risks, providing risk response strategies and selecting the most appropriate risk response strategies according to the goals and objectives. Therefore, the introduction of a new fuzzy expert system for project portfolio risk management is a considerable gap in the relevant literature and there exists an urgent practical need that the current study seeks to fulfill the existing gap by presenting a new fuzzy expert system for project portfolio risk management and implementing it within a real case study. In this paper, the main risk factors are identified through library search and expert judgment and the most important risk factors are determined using the developed DEMATEL method. Then, a combined fuzzy FMEA-AHP method is exploited to evaluate these major risk factors. Finally, a fuzzy multi-objective mathematical programming model is developed to find the optimal risk response strategies for the case study.

RESEARCH METHOD

In this research, library resources, articles, required books and also reputable scientific sites were used in order to collect information on the theoretical foundations and literature of the research. In order to collect the data required for the research, the opinions of experts active in the case study holding were extracted. The main risk factors in the project portfolio of a construction company were identified using the developed DEMATEL method and in Excel software. Afterward, using fuzzy FMEA methods in Excel and AHP method in Expert Choice software, identified risk factors were evaluated and the most important risk factors are determined. In the next step, the optimal response strategies to the main risk factors were obtained using the proposed mathematical model and solving it with GAMS (General Algebraic Modeling System) optimization software. Figure. 1 presents the conceptual model of the research.

According to Figure 1, this research is conducted in four steps:

Step 1: Developing the project portfolio risk management plan in the holding under study.

Step 2: Identifying the portfolio risks using expert judgement as well as the mutual relationships among risks using the developed DEMATEL method.

Step 3: Analyzing the identified risks using Fuzzy FMEA and AHP methods.

Step 4: Developing a mathematical programming model to select the most appropriate risk response strategies.

The details of each step are given separately in Figure 1.

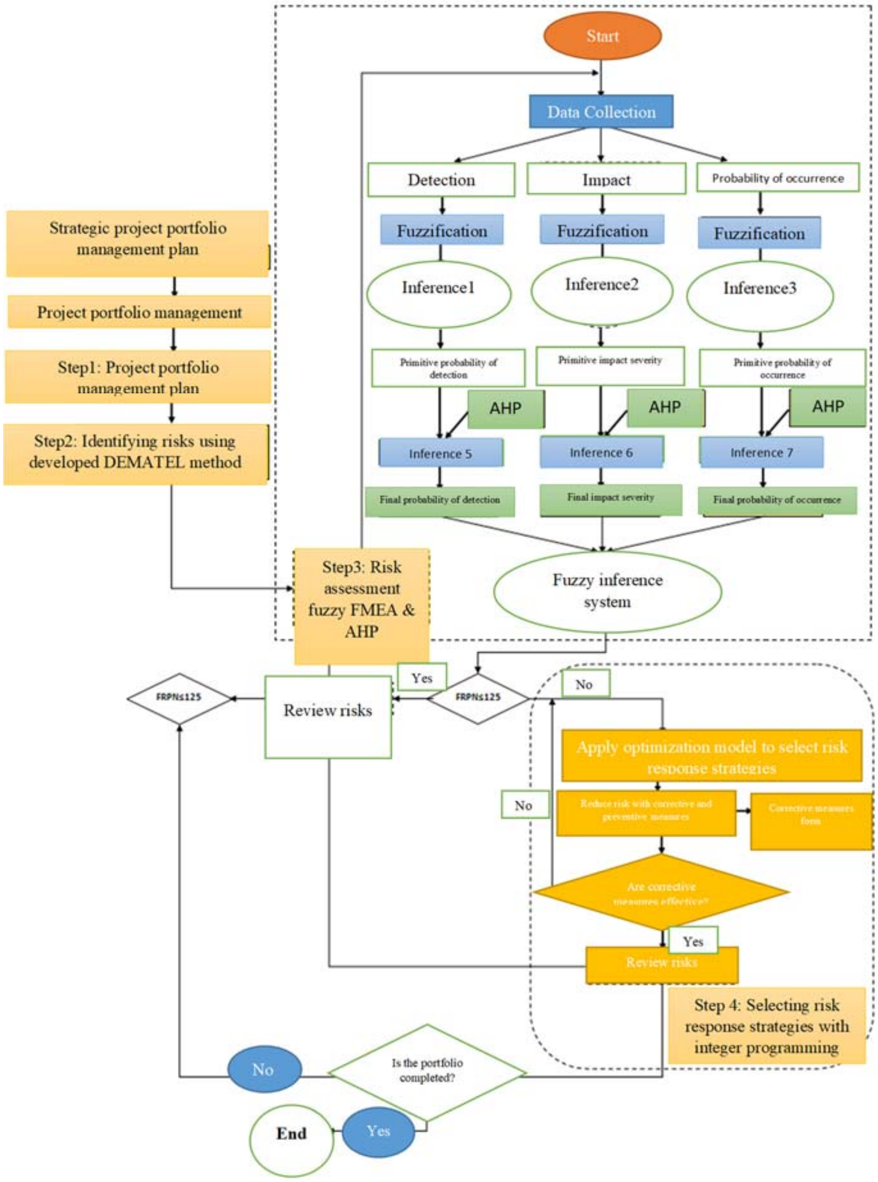

Figure (1): Flowchart of proposed fuzzy expert system

The Mathematical Programing Model

The multi-objective mathematical programming model is developed for selecting the optimal project portfolio during a planning time period taking different constraints into account. The substantial concepts including project environment, Work Breakdown Structure (WBS), risk occurrence, risk consequence and risk responses are considered for selecting project risk response strategies. Three main project goals and objectives of time, cost and quality are taken into account. Figure 2 depicts the process of selecting the best project, in which there is a strategy to respond to the r^{th} risk factor. In other words, N projects must be evaluated together with their risk responses in order to select the optimal project portfolio including j projects.

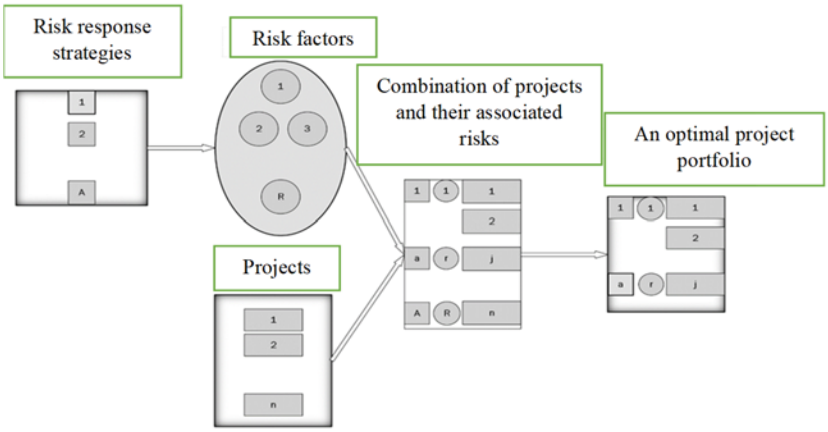

Figure (2): The process of selecting response strategies for project portfolio

The sets, parameters and variables of the proposed mathematical model are defined and described as follows:

Sets

Projects ($j = 1,2,\ldots, n$)	j
Human resources ($I = 1,2,\ldots, m$)	i
Machines ($k = 1,2,\ldots, s$)	k
Raw materials ($o = 1,2,\ldots, z$)	o
Time period ($t = 1,2,\ldots, T$)	t
Work activities ($w = 1,2,\ldots, W$)	w
Risk incidents ($r = 1,2,\ldots, R$)	r
Candidate response to risk factor ($a = 1,2,\ldots, A$)	a
A set of all pairs of strategies that conflict with each other	$\overleftrightarrow{M}$
A set of all pairs of strategies that are coordinated with each other and have a constructive relationship	$\bar{M}$

Parameters

Maximum human resource type I in time period t in terms of person – hours	H_{it}
Human resources required for type I for project j on an individual-hour basis	h_{ij}
Maximum machine-clock available type k in time period t	$\widetilde{M}_{kt}$
Machine-clock required type k for project j	m_{kj}
Maximum required raw materials of type o in time period t	R_{ot}
Maximum raw materials required for type o for the project j	r_{oj}
Maximum hourly budget available for project j in time period t	$\tilde{B}_{jt}$
Hourly cost of human resources type I in time period t	$\tilde{C}_{it}$
Hourly cost of type k car in time period t	$\tilde{C}_{kt}$

Cost per unit of type o raw materials in time period *t*	$\tilde{C}_{ot}$
w th work activity	W_w
r th risk response	R_r
a th candidate risk response strategy	A_a
The cost of implementing risk response strategy *a*	C_a
The hourly cost of implementing risk response strategy *a*	$\tilde{C}_a$
Net profit of project *j* in time period *t*	$\tilde{p}_{jt}$
Rate of return for project *j* in time period *t*	I_{jt}
Minimum attractive rate of return on investment of project in time period *t*	MAR
Estimated quality loss for Wth work when rth risk factor occurs	q_r^w
Estimated quality loss for wth work activity after implementing risk response *a* for rth risk factor	q_{ar}^w
Maximum allowable reduction limit for project quality level	Q_{max}
The interval between the completion of the work activity and the beginning of the next work activity	ε^w
Estimated number of days for doing wth work if rth risk factor occurs	s_r^w
Estimated number of days for doing wth work after applying the am risk response to the rth risk factor	s_{ar}^w
Maximum allowable quality reduction limit of wth work activity so that it does not affect the execution of its immediate successor activity	δ^w
Maximum hourly delay in project completion time	$\acute{T}_{max}$
Maximum allowable delay for project completion time	T_{max}
The hourly effect of the estimated risk response after applying the am risk response to the rth risk factor	$\tilde{e}_{ar}$
Duration of project *j* in time period t. The problem of selecting project risk response strategies	d_{jt}

Decision Variables

The binary variable equals 1 if project *j* is selected for investment in period *t*; otherwise 0.	x_{jt}
The binary variable equals 1 if response strategy *a* is implemented for risk factor *r* in project *j*; otherwise 0	z_{jar}

The mathematical model includes two objective functions. Objective function (1) maximizes the net profit of project portfolio selection and the impact of all risk response strategies for each portfolio selection project. Objective function (2) seeks to minimize the total cost of selected projects. In this objective function, the first section is related to the cost of human resources, the second section is associated with the cost of machinery, the third section shows the cost of raw materials and the last section represents the implemented risk response strategies. The proposed mathematical programming model is as follows:

$$Max\ Z_1 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \times \tilde{p}_{jt} + \sum_{j=1}^{n}\sum_{a=1}^{A}\sum_{r=1}^{R} z_{jar} \times \tilde{e}_{ar} \quad (1)$$

$$Min\ Z_2 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{i=1}^{m} h_{ij}\ .\tilde{C}_{it} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{k=1}^{s} m_{kj}\ .\tilde{C}_{kt} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{o=1}^{z} r_{oj}\ .\tilde{C}_{ot} + \sum_{j=1}^{n}\sum_{a=1}^{A} \tilde{C}_a \max_r z_{jar} \quad (2)$$

S.t:

$$\sum_{t=1}^{T} x_{jt} \leq 1 \qquad \forall\ j = 1,2,\dots,n \quad (3)$$

$$\sum_{t=1}^{T}(t+d_{jt}).x_{jt} \le T_{max} \qquad \forall\ j=1,2,\dots,n \tag{4}$$

$$\sum_{j=1}^{n} h_{ij}x_{jt} \le H_{it} \qquad \forall\ i=1,2,\dots,m, \quad t=1,2,\dots,T \tag{5}$$

$$\sum_{j=1}^{n} m_{kj}x_{jt} \le M_{kt} \qquad \forall\ k=1,2,\dots,s, \quad t=1,2,\dots,T \tag{6}$$

$$\sum_{j=1}^{n} r_{oj}x_{jt} \le R_{ot} \qquad \forall\ O=1,2,\dots,z, \quad t=1,2,\dots,T \tag{7}$$

$$\left(\sum_{i=1}^{m} h_{ij}\ .\tilde{C}_{it} + \sum_{k=1}^{s} m_{kj}\ .\tilde{C}_{kt} + \sum_{o=1}^{z} r_{oj}\ .\tilde{C}_{ot}\right) \times x_{jt} < \tilde{p}_{jt}\ ,\ j=1,2,\dots,n \qquad \forall\ t \tag{8}$$

$$\sum_{j=1}^{n}\sum_{a=1}^{A} \tilde{C}_a \max_{r} z_{jar} + \left[\sum_{i=1}^{m} h_{ij}\ \tilde{C}_{it} + \sum_{k=1}^{s} m_{kj}\ \tilde{C}_{kt} + \sum_{o=1}^{z} \tilde{C}_{ot}\ r_{oj}\right] \times x_{jt} \le \tilde{B}_{jt} \qquad \forall\ r,j,t \tag{9}$$

$$\sum_{r=1}^{R} s_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(s_{ar}^w z_{jar}\right) \le \varepsilon^w \qquad \forall\ j=1,\dots,n \qquad w=1,2,\dots,W-1 \tag{10}$$

$$\sum_{r=1}^{R} q_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(q_{ar}^w z_{jar}\right) \le \delta^w \qquad \forall\ j=1,\dots,n \qquad w=1,2,\dots,W-1 \tag{11}$$

$$\sum_{r=1}^{R} s_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(s_{ar}^W z_{jar}\right) \le \acute{T}_{max} \qquad \forall\ j=n \tag{12}$$

$$\sum_{r=1}^{R} q_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(q_{ar}^W z_{jar}\right) \le Q_{max} \qquad \forall\ j=n \tag{13}$$

$$\sum_{j=1}^{n} x_{jt}.(MARR_t - I_{jt}) \le 0 \qquad \forall\ t=1,2,\dots,T \tag{14}$$

$$\sum_{j=1}^{n} x_{jt} \ge 0 \qquad \forall\ t=1,2,\dots,T \tag{15}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} \le 1 \quad (A_a, A_{\acute{a}}) \in \overleftrightarrow{M} \quad \forall\ j=1,\dots,n \quad a,\acute{a}=1,\dots,A \quad ,r,\acute{r}=1,\dots,R \tag{16}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} = 1 \quad (A_a, A_{\acute{a}}) \in \overleftrightarrow{M} \quad \forall\ j=1,\dots,n \quad a,\acute{a}=1,\dots,A \quad ,r,\acute{r}=1,\dots,R \tag{17}$$

$$z_{jar} - z_{j\acute{a}\acute{r}} \le 0 \quad (A_a, A_{\acute{a}}) \in \overline{M} \quad \forall\ j=1,\dots,n \quad a,\acute{a}=1,\dots,A \quad ,r,\acute{r}=1,\dots,R \tag{18}$$

$$z_{jar}, z_{j\acute{a}\acute{r}} \in \{0,1\}, \quad \forall\ j=1,\dots,n \quad a,\acute{a}=1,\dots,A \quad ,r,\acute{r}=1,\dots,R \tag{19}$$

$$x_{jt} \in \{0,1\} \qquad \forall\ j=1,2,\dots,n, \qquad t=1,2,\dots,T \tag{20}$$

Constraint (3) ensures that the selection of each project occurs only once in the planning time period. Constraint (4) states that the combined time of each selected project is less than the total project planning period and the maximum delay for project completion time. Constraints (5) to (7) express the maximum constraints of all three types of resources. Constraint (5) states that the number of human resources of any type required for projects in the selection period cannot exceed the maximum human resources available for all types and in all planning periods. Constraint (6) ensures that all machine-hour resources in all types and for projects in the selection period do not exceed the maximum machine-hour resources available for all types and in all planning periods. Constraint (7) ensures that all raw material resources of all types required for projects in the selection period do not exceed the maximum raw material resources of all types and in all time periods.

Constraint (8) ensures that the total cost of each selected project is less than the profit of that project for all planning periods. Constraint (9) ensures that the total cost of the selected project including human resources, machinery, raw materials and implementing risk response strategies is less than the project budget for all projects and in all planning periods. Constraint (10) states that in each project, each working activity (except the last activity) is completed at the specified time, otherwise this activity has no effect on the start times of the next activity in that project. Constraint (11) ensures that in each project, each activity (except the last activity) has to be maintained at a certain quality level, otherwise that activity has a negative effect on its immediate successor activity.

Constraint (12) indicates that in each project, the last activity must be completed within the specified time period. Constraint (13) shows that in each project, the last activity must meet the project quality standards. Constraint (14) ensures that a project is selected if its internal rate of return on investment is greater than or equal to the lowest attractive rate of return on investment. Constraint (15) indicates that a project can be selected in each time period. Constraints (16) to (18) are related to the risk response strategies. Constraint (16) states that strategies $A_{\acute{a}}$ and A_a in each project are mutually exclusive and conflicting. Constraint (17) states that if strategies $A_{\acute{a}}$ and A_a in each project conflict or overlap, only one of them must be selected. Constraint (18) states that projects cooperate, where if one strategy is selected, another specific strategy must be selected too. Constraint (19) describes the binary variables for each project and constraint (20) refers to the binary decision variables.

Fuzzy and Defuzzified Mathematical Programming Model by Fuzzy Rank Function Model

The fuzzy logic theory permits the crisp number to be replaced with an upper limit, a lower limit and an average estimate and thereby provides an approach for solving the problems in the absence of complete or accurate information. Considering the inaccurate and uncertain nature and characteristics of the data involved with real-world problems, the present work employs the upper limit, lower limit and average estimate of crisp numbers to develop a fuzzy model which is more appropriate for dealing with vague and uncertain data.

The left and right developed matrices of a={a_j} are first shown by n={n_j} and m={m_j}. Now, $\tilde{a}_j$ is defined as $\tilde{a}_j = (a_j, m_j, n_j)$.

Rank function is a mapping which projects fuzzy numbers on real numbers. Fuzzy rank function model has been presented as a successful and very practical method for dealing with the uncertainty of parameters. This function considers three possible states including best state, normal state and worst state for each parameter. This method uses a mathematical function to convert fuzzy numbers into crisp numbers according to the following equation (Mostafaeipour et al., 2017).

$$R: F(R) \rightarrow R$$
$$R(\tilde{a}_j) = \frac{(a_j - m_j) + 2a_j + (a_j + n_j)}{a} \cong \frac{a^l + a^u}{2} \quad (21)$$
$$\forall \tilde{a}_j = (a_j, m_j, n_j)$$

For more information about the fuzzy ranking function, refer to Mostafaeipour et al. (2017).

Here, the fuzzy mathematical programming model is presented as follows:

$$Max\ Z_1 \approx \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \times \widetilde{ph}_{jt} + \sum_{j=1}^{n}\sum_{a=1}^{A}\sum_{r=1}^{R} z_{jar} \times \widetilde{eh}_{ar} \quad (22)$$

$$Min\ Z_2 \approx \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{i=1}^{m}\tilde{h}_{ij}\ .\widetilde{CH}_{it} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{k=1}^{s}\widetilde{m}_{kj}\ .\widetilde{CH}_{kt} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{o=1}^{z}\tilde{r}_{oj}\ .\widetilde{CH}_{ot} + \sum_{j=1}^{n}\sum_{a=1}^{A}\widetilde{CH}_a \max_r z_{jar} \tag{23}$$

s.t:

$$\sum_{t=1}^{T} x_{jt} \ll 1 \qquad \forall\ j = 1,2,\ldots,n \tag{24}$$

$$\sum_{t=1}^{T}(\tilde{t} + \tilde{d}_{jt})\ .x_{jt} \ll \tilde{T}_{max} \qquad \forall\ j = 1,2,\ldots,n \tag{25}$$

$$\sum_{j=1}^{n}\tilde{h}_{ij}x_{jt} \ll \widetilde{H}_{it} \qquad \forall\ i = 1,2,\ldots,m\,,\quad t = 1,2,\ldots,T \tag{26}$$

$$\sum_{j=1}^{n}\widetilde{m}_{kj}x_{jt} \ll \widetilde{MH}_{kt} \qquad \forall\ k = 1,2,\ldots,s\,,\quad t = 1,2,\ldots,T \tag{27}$$

$$\sum_{j=1}^{n}\tilde{r}_{oj}x_{jt} \ll \tilde{R}_{ot} \qquad \forall\ O = 1,2,\ldots,z\,,\quad t = 1,2,\ldots,T \tag{28}$$

$$\left(\sum_{i=1}^{m}\tilde{h}_{ij}\ .\widetilde{CH}_{it} + \sum_{k=1}^{s}\widetilde{m}_{kj}\ .\tilde{C}H_{kt} + \sum_{o=1}^{z}\tilde{r}_{oj}\ .\widetilde{CH}_{ot}\right)\times x_{jt} < \tilde{p}h_{jt}\ ,\ \ j = 1,2,\ldots,n \qquad \forall\ t \tag{29}$$

$$\sum_{j=1}^{n}\sum_{a=1}^{A}\widetilde{CH}_a \max_r z_{jar} + \left[\sum_{i=1}^{m}\tilde{h}_{ij}\ \widetilde{CH}_{it} + \sum_{k=1}^{s}\widetilde{m}_{kj}\ \widetilde{CH}_{kt} + \sum_{o=1}^{z}\tilde{C}_{ot}\,\tilde{r}_{oj}\right]\times x_{jt} \ll \widetilde{BH}_{jt} \qquad \forall\ r,j,t \tag{30}$$

$$\sum_{r=1}^{R}\tilde{s}_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\tilde{s}_{ar}^w z_{jar}\right) \ll \tilde{\varepsilon}^w \qquad \forall\ j = 1,\ldots,n \qquad w = 1,2,\ldots,W-1 \tag{31}$$

$$\sum_{r=1}^{R}\tilde{q}_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\tilde{q}_{ar}^w z_{jar}\right) \ll \tilde{\delta}^w \qquad \forall\ j = 1,\ldots,n \qquad w = 1,2,\ldots,W-1 \tag{32}$$

$$\sum_{r=1}^{R}\tilde{s}_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\tilde{s}_{ar}^W z_{jar}\right) \ll \tilde{T}H_{max} \qquad \forall\ j = n \tag{33}$$

$$\sum_{r=1}^{R}\tilde{q}_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\tilde{q}_{ar}^W z_{jar}\right) \ll \tilde{Q}_{max} \qquad \forall\ j = n \tag{34}$$

$$\sum_{j=1}^{n} x_{jt}\ .(\widetilde{MAR}R_t - \tilde{I}_{jt}) \ll 0 \qquad \forall\ t = 1,2,\ldots,T \tag{35}$$

$$\sum_{j=1}^{n} x_{jt} \gg 0 \qquad \forall\ t = 1,2,\ldots,T \tag{36}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} \ll 1 \qquad (A_a, A_{\acute{a}}) \in \overleftrightarrow{M} \qquad \forall\ j = 1,\ldots,n \quad a,\acute{a} = 1,\ldots,A \quad ,r,\acute{r} = 1,\ldots,R \tag{37}$$

$$z_{jar} - z_{j\acute{a}\acute{r}} \ll 0 \qquad (A_a, A_{\acute{a}}) \in \bar{M} \quad \forall\, j = 1, \dots, n \quad a, \acute{a} = 1, \dots, A \quad , r, \acute{r} = 1, \dots, R \tag{38}$$

$$z_{jar}, z_{j\acute{a}\acute{r}} \in \{0,1\}, \quad \forall\, j = 1, \dots, n \quad a, \acute{a} = 1, \dots, A \quad , r, \acute{r} = 1, \dots, R \tag{39}$$

$$x_{jt} \in \{0,1\} \qquad \forall\, j = 1,2, \dots, n, \qquad t = 1,2, \dots, T \tag{40}$$

Fuzzy mathematical programming model is defuzzified using the fuzzy rank function model, which is presented as shown below:

$$Max\, Z_1 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \times \acute{ph}_{jt} + \sum_{j=1}^{n}\sum_{a=1}^{A}\sum_{r=1}^{R} z_{jar} \times \acute{eh}_{ar} \tag{41}$$

$$Min\, Z_2 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{i=1}^{m} \acute{h}_{ij}\, .\acute{CH}_{it} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{k=1}^{s} \acute{m}_{kj}\, .\acute{CH}_{kt} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \sum_{o=1}^{z} \acute{r}_{oj}\, .\acute{CH}_{ot} + \sum_{j=1}^{n}\sum_{a=1}^{A} \acute{CH}_a \max_r z_{jar} \tag{42}$$

S.t:

$$\sum_{t=1}^{T} x_{jt} \le 1 \qquad \forall\, j = 1,2, \dots, n \tag{43}$$

$$\sum_{t=1}^{T} (\acute{t} + \acute{d}_{jt}) \,.\, x_{jt} \le \acute{T}_{max} \qquad \forall\, j = 1,2, \dots, n \tag{44}$$

$$\sum_{j=1}^{n} \acute{h}_{ij} x_{jt} \le \acute{H}_{it} \qquad \forall\, i = 1,2, \dots, m, \quad t = 1,2, \dots, T \tag{45}$$

$$\sum_{j=1}^{n} \acute{m}_{kj} x_{jt} \le \acute{MH}_{kt} \qquad \forall\, k = 1,2, \dots, s, \quad t = 1,2, \dots, T \tag{46}$$

$$\sum_{j=1}^{n} \acute{r}_{oj} x_{jt} \le \acute{R}_{ot} \qquad \forall\, O = 1,2, \dots, z, \quad t = 1,2, \dots, T \tag{47}$$

$$\left(\sum_{i=1}^{m} \acute{h}_{ij}\, .\acute{CH}_{it} + \sum_{k=1}^{s} \acute{m}_{kj}\, .\acute{CH}_{kt} + \sum_{o=1}^{z} \acute{r}_{oj}\, .\acute{CH}_{ot}\right) \times x_{jt} < \acute{ph}_{jt}\,, \quad j = 1,2, \dots, n \qquad \forall\, t \tag{48}$$

$$\sum_{j=1}^{n}\sum_{a=1}^{A} \acute{CH}_a \max_r z_{jar} + \left[\sum_{i=1}^{m} \acute{h}_{ij}\, \acute{CH}_{it} + \sum_{k=1}^{s} \acute{m}_{kj}\, \acute{CH}_{kt} + \sum_{o=1}^{z} \acute{CH}_{ot}\, \acute{r}_{oj}\right] \times x_{jt} \le \acute{BH}_{jt} \qquad \forall\, r, j, t \tag{49}$$

$$\sum_{r=1}^{R} \acute{s}_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A} \left(\acute{s}_{ar}^w z_{jar}\right) \le \acute{\varepsilon}^w \qquad \forall\, j = 1, \dots, n \qquad w = 1,2, \dots, W-1 \tag{50}$$

$$\sum_{r=1}^{R} \acute{q}_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A} \left(\acute{q}_{ar}^w z_{jar}\right) \le \tilde{\delta}^w \qquad \forall\, j = 1, \dots, n \qquad w = 1,2, \dots, W-1 \tag{51}$$

$$\sum_{r=1}^{R} \acute{s}_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\acute{s}_{ar}^W z_{jar}\right) \leq \acute{TH}_{max} \qquad \forall\, j = n \tag{52}$$

$$\sum_{r=1}^{R} \acute{q}_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(\acute{q}_{ar}^W z_{jar}\right) \leq \acute{Q}_{max} \qquad \forall\, j = n \tag{53}$$

$$\sum_{j=1}^{n} x_{jt} \,.\, (M\acute{A}RR_t - \tilde{I}_{jt}) \leq 0 \qquad \forall\, t = 1,2,\dots,T \tag{54}$$

$$\sum_{j=1}^{n} x_{jt} \geq 0 \qquad \forall\, t = 1,2,\dots,T \tag{55}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} \leq 1 \quad (A_a, A_{\acute{a}}) \in \overleftrightarrow{M} \quad \forall\, j = 1,\dots,n \quad a,\acute{a} = 1,\dots,A \quad ,r,\acute{r} = 1,\dots,R \tag{56}$$

$$z_{jar} - z_{j\acute{a}\acute{r}} \leq 0 \quad (A_a, A_{\acute{a}}) \in \bar{M} \quad \forall\, j = 1,\dots,n \quad a,\acute{a} = 1,\dots,A \quad ,r,\acute{r} = 1,\dots,R \tag{57}$$

$$z_{jar}, z_{j\acute{a}\acute{r}} \in \{0,1\} \quad \forall\, j = 1,\dots,n \quad a,\acute{a} = 1,\dots,A \quad ,r,\acute{r} = 1,\dots,R \tag{58}$$

$$x_{jt} \in \{0,1\} \qquad \forall\, j = 1,2,\dots,n, \qquad t = 1,2,\dots,T \tag{59}$$

The diffuszzified mathematical programming model is coded and solved in GAMS software to obtain the best risk response strategies.

RESULTS AND DISCUSSION

According to the study conducted on one of the large construction companies in Iran as a case study; there are four projects in this portfolio including A, B, C and D with the following data.

Table 2. Data of four projects portfolio in Iran

Project	Type	Estimated Budget (US$)	Estimated Duration (months)
A	Residential building	1,800,000	42
B	Residential building	1,350,000	36
C	Shopping mall	17,500,000	60
D	Bridge construction	4,750,000	24

23 different risk factors were identified in these four projects through the opinions of the experts including 11 senior managers, project managers, deputies and professionals working in this holding.

Women and men comprised 36% and 64% of the statistical sample size, respectively. The age group of 30-40 years was the most frequent group of age with a percentage of 54%. The frequency of different qualifications was as follows: 4 bachelors, 5 masters and 2 doctorates. Respondents' work experience was as follows: under 5 years (45%), between 5 and 10 years (18%), between 11 and 15 years (27%) and over 15 years (10%).

In the first stage, the risks were identified by reviewing related studies and interviewing the experts of the organization and classified into two different groups: (1) Internal risks (managerial, legal and financial): These risks are more identifiable and manageable within the organization and not paying attention to them can make it difficult for projects to achieve their goals. (2) External risks (political, economic, social and climatic): These risks are more out of the control of the organization and can affect the portfolio goals.

Due to the diversity and extent of internal and external risks, these risks have been studied and analyzed in this study in the following categories, as shown in Figure 3.

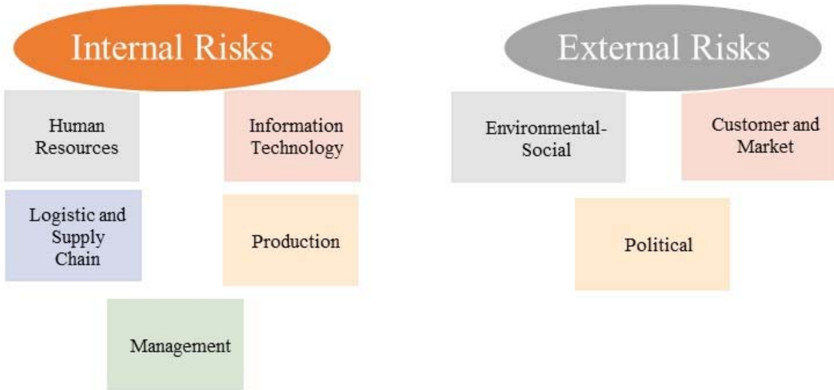

Figure (3): Risk classification (Internal and External Risks)

Internal Risk

Information Technology (IT) Risks: The existence of appropriate IT infrastructure to support the activities of the project and portfolio should be emphasized. IT can have positive or negative effects on the success of projects. These risks are examined in four sections: risk of not having access to information (R1), information system failure risk (R3), information system security risk (R5) and information accuracy risk (R6) (Unger et al., 2012; Ghasemi et al., 2018).

Human Resources Risks: These risks refer to programs and processes related to the organization's employees that, if properly managed, will place the organization among the market leaders. These risks are defined as human resources risks (R12) (Becker and Smidt, 2016).

Production-related Risks: These risks are analyzed in three sub-groups: production quality risks (R15), technical risks (R19) and safety risks (R21). Production quality risks are related to the quantitative tracking of quality criteria in projects and products (Qing et al., 2014). Technical risk includes lack of initial feasibility study of projects and preparation of documents, lack of attention to the required network of mechanical facilities and equipment, lack of access to appropriate technical tools and equipment and non-compliance of initial studies with technical specifications of projects (Nazari and Jaberi, 2015). Safety risks are related to occupational accidents and injuries in the workplace (Chopra and Sodhi, 2004; Badri et al., 2012; Khan et al., 2015, Khalilzadeh et al., 2020).

Logistics and Supply Chain Risks: These risks affect the final output of projects and ultimately influence customers and stakeholders. Identifying and managing these risks is essential to gaining a competitive advantage and responding appropriately to environmental opportunities and threats. These risks are examined in five sections: logistics risks (R10), supply and distribution cost risks (R11), procurement risks (R13), material order risks (R20), supply performance risks (R22) and inventory risk (R23) (Chopra and Sodhi, 2004; Finch, 2004; Kumar and Park, 2019).

Management Risks: These risks (R16) refer to risk assessment and control activities that are reviewed by senior management (Micán et al., 2019).

External Risk

Customer and Market Risks: These types of risks are examined in four sections: market risks (R2) are related to the potential profit or loss due to changes in market conditions, such as interest rates, commodity prices and exchange rates and other economic and financial variables, such as stock prices and currency exchange rate (Nason, 2011). Competitive risks (R8) are related to the activities of competitors in the market and the share and percentage of each domestic and foreign markets (Micán et al., 2019). Risks of customer expectations (R18) are related to changes in customer interests about the product (Ryals, 2003). Contractual risks (R14) are related to changes in commercial contracts with suppliers (Micán et al., 2019).

Environmental-Social Risks: Environmental risks (R9) are related to weather conditions and environmental issues surrounding the project portfolio (Razi et al., 2015). Social risks (R17) represent the benefit and value creation for project stakeholders. One of the most important stakeholders of any project is the target community receiving the services or products created from that project. Project implementation plays an important role in social sustainability (Micán et al., 2019).

Political Risks: One of the types of risks that always affect companies is political risks. These risks indicate the change of political variables in a country and can be examined in two parts: risks of laws, regulations and warranties (R4) that arise due to changes in various laws and the effects that these laws and regulations have on the project portfolio (Nazari and Jaberi, 2015). Political risks (R7) arise from political events and unfavorable conditions in international affairs. These risks are related to the variables of political stability, political freedom, sanctions and government reactions (Razi et al., 2015; Ghalia et al., 2019).

A researcher-made questionnaire was used to collect the data required for this research. Then, the developed DEMATEL method was used to determine the relationships among these risk factors. Subsequently, the fuzzy FMEA and AHP methods were applied to assess and rank the identified risk factors. Finally, the fuzzy multi-objective mathematical programming model was proposed to obtain the optimal risk response strategies. The analysis of each section is presented below.

Determination of Causal Relationships among Risk Factors with the DEMATEL Method

In this study, a total number of 23 risk factors were identified through a review of the research literature and expert judgment for the holding as a case study. The developed DEMATEL method was used to identify and select the main risk factors. The findings of this method are provided as follows. Table 3 presents the set of identified risk factors.

Table 3. Initial risk factors identified by experts

Description	No.	Description	No.
Risk of not having access to information	1	Procurement risk	13
Market risk	2	Contractual risk	14
Risk of information system failure	3	Production quality risk	15
Risk of laws, regulations and warranties	4	Risk management	16
Information system security risk	5	Social risk	17
Information accuracy risk	6	Risk of customer expectations	18
Political risk	7	Technical risk	19
Competition risk	8	Material order risk	20
Environmental risk	9	Safety risk	21
Logistics risk	10	Supply performance risk	22
Risk of procurement and distribution costs	11	Inventory risk	23
Human resource risk	12		

Then, the most important risk factors were identified using the DEMATEL method and Excel software. A questionnaire using the DEMATEL method was used to collect data. 8 risk factors out of 23 identified risk factors were selected as the most important risk factors for assessment. Table 4 shows the findings of the DEMATEL method as well as the list of 8 final risk factors.

Also, the status of each of the 8 risk factors identified on the causal relationships chart in the DEMATEL method is respectively shown in Figure 4. According to Figure 4, 2 of the 8 identified risk factors have high impacts and the rest of the risk factors have almost the same scores.

Table 4. Final risk factors by DEMATEL method

Causal relationships of model criteria	Risk description	D	R	D+R	D-R
Risk 1	Risk of not having access to information	9.974	11.408	-1.434	21.381
Risk 2	Market risk	10.147	10.877	-0.729	21.024
Risk 3 (C1)	Risk of information system failure	3.178	2.252	5.430	0.926
Risk 4 (C2)	Risk of laws, regulations and warranties	2.957	2.514	5.471	0.443
Risk 5	Information system security risk	10.056	10.586	-0.53	20.642
Risk 6	Information accuracy risk	9.806	10.480	-0.675	20.286
Risk 7	Political risk	10.230	10.414	-0.184	20.644
Risk 8	Competition risk	10.891	10.644	0.2472	21.535
Risk 9	Environmental risk	9.980	10.775	-0.795	20.756
Risk 10	Logistics risk	9.875	10.588	-0.713	20.463
Risk 11 (C3)	Risk of procurement and distribution costs	2.763	2.850	5.613	-0.088
Risk 12 (C4)	Human resource risk	2.797	3.112	5.909	-0.315
Risk 13 (C5)	Procurement risk	3.016	3.055	6.071	-0.040
Risk 14	Contractual risk	10.214	10.649	-0.435	20.863
Risk 15	Production quality risk	10.221	10.219	0.0016	20.44
Risk 16	Risk management	10.810	11.194	-0.384	22.005
Risk 17	Social risk	9.979	10.451	-0.472	20.43
Risk 18	Risk of customer expectations	10.149	10.245	-0.096	20.395
Risk 19 (C6)	Technical risk	2.712	3.076	5.788	-0.364
Risk 20	Material order risk	10.847	10.500	0.3469	21.348
Risk 21 (C7)	Safety risk	2.927	3.489	6.416	-0.562
Risk 22 (C8)	Supply performance risk	2.797	2.570	5.367	0.227
Risk 23	Inventory risk	10.254	10.024	0.2309	20.278

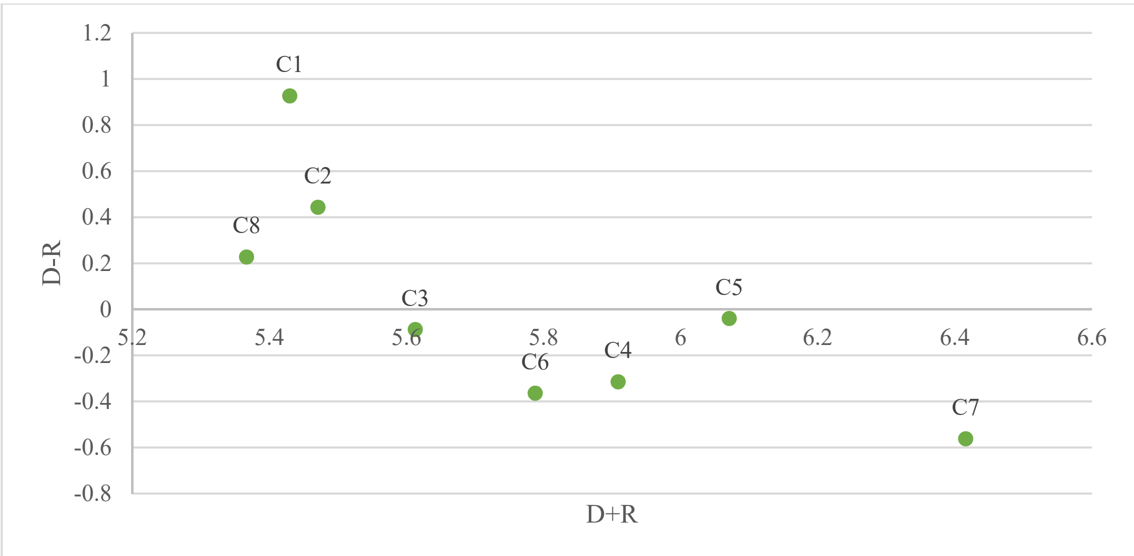

Figure (4): Status of each of the identified risk factors

Then, the identified risk factors were assessed using the combination of the fuzzy FMEA and AHP methods.

Ranking Main Risk Factors Using the AHP Method

The concept of “inconsistency rate" in the AHP method shows the reliability of the designed questionnaires for analyzing the set of risk factors, which must be less than 0.1 for each questionnaire to confirm the reliability of the collected questionnaires (Fattahi and Khalilzadeh, 2018). As shown in Figure 5, the inconsistency rate is 0.00567, meaning that the reliability of the questionnaire is confirmed. Also, the weights of the risk factor of information system failure, the risk of laws, regulations and warranties, the risk of procurement and distribution costs, the procurement risk, the human resource risk, the technical risk, the safety risk and the supply performance risk are obtained to be 0.144, 0.293, 0.162, 0.131, 0.129, 0.065, 0.035 and 0.040, respectively, as shown in Table 5 and Figure 5.

Table 5. Rating main risk factors with AHP

No.	Factor	Symbol	Weight	rate
1	Risk of information system failure	Risk 1	0.144	3
2	Risk of laws, regulations and warranties	Risk 2	0.293	1
3	Risk of procurement and distribution costs	Risk 3	0.162	2
4	Procurement risk	Risk 4	0.131	4
5	Human resource risk	Risk 5	0.129	5
6	Technical risk	Risk 6	0.065	6
7	Safety risk	Risk 7	0.035	8
8	Supply performance risk	Risk 8	0.040	7

As a result, the risk of rules and regulations and terms and conditions and quarantines is top-ranked and most significant risk factor.

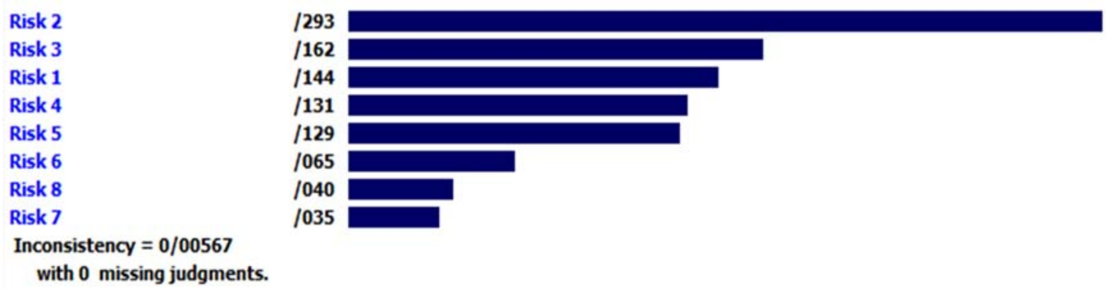

Figure (5): Weights of main risk factors obtained by the AHP method

Evaluation of Identified Risk Factors with the FMEA Method

According to the framework provided for the steps of the present study, after identifying the risks in the selected projects of the holding, the FMEA method along with the fuzzy inference method are used to assess risk factors in three categories of probability of occurrence, severity and detection. After receiving the opinions of experts, the opinions were averaged and according to the steps of the FMEA method, the initial values for the probability of occurrence (O), severity (S) and detection (D) of each risk factor were calculated. This process is performed for all risks and therefore the value of RPN is obtained for each of the 8 risks. According to Table 6, the highest probability of occurrence belongs to the third risk (risk of procurement and distribution costs) which is approximately equal to 70%, the severity of the initial effect is approximately equal to 42% and the probability of detection is nearly equal to 28%. Also, risks 2 and 7 (risk of laws, regulations and warranties and safety risk) have the lowest probability of occurrence. In addition, the RPN values of all risks are quite low, which indicates that the identified risks are not acute.

Table 6. Initial RPN values of risk factors

	Detection	Severity	Probability of Occurrence	RPN Value
Risk 1	0.128439	0.328327	0.645427	2.72
Risk 2	0.047468	0.130111	0.328828	0.20
Risk 3	0.281148	0.419472	0.696464	8.21
Risk 4	0.167721	0.319074	0.508969	2.72
Risk 5	0.165157	0.135541	0.446520	1.00
Risk 6	0.082566	0.108606	0.596590	0.53
Risk 7	0.231823	0.169185	0.322580	1.50
Risk 8	0.136038	0.151959	0.410640	0.84

After obtaining the RPN value for each risk, multiplying the weights (gained by the AHP method) by the values obtained by the FMEA method, new values for the criteria of probability of occurrence, severity and detection of each risk are computed. Table 7 presents the obtained values for each risk separately.

Table 7. Final RPN values of risk factors

	Detection	Severity	Probability of Occurrence	RPN Value
Risk 1	0.172347	0.300206	0.728056	4.89
Risk 2	0.058898	0.153431	0.355433	0.32
Risk 3	0.283068	0.497574	0.788002	11.09
Risk 4	0.157868	0.407216	0.481772	3.09
Risk 5	0.168191	0.131462	0.562549	1.24
Risk 6	0.129862	0.102462	0.732963	0.97
Risk 7	0.347929	0.258889	0.496300	4.47
Risk 8	0.151389	0.179119	0.722283	1.95

According to Table 7, the highest probability of occurrence of risk is about 78% for the third risk, the greatest severity is nearly equal to 49% for the third risk and the highest risk detection is about 28% for the third risk. Therefore, the overall results of rankings obtained by both AHP and FMEA methods are the same and only the numbers are different, which clearly demonstrates the validity of the proposed method.

Since the RPN values for the identified risks which were removed from the list of final risk factors are less than 125, the outputs of this step were confirmed and we proceed to the final step in order to select the strategies to respond to the more important risk factors.

Findings of the Proposed Multi-objective Mathematical Model

In the next step, the optimal risk response strategies were selected using the proposed fuzzy multi-objective mathematical programming model. The purpose of bi-objective optimization model is to select the most appropriate risk response strategies. This model was coded and solved within 7.2 seconds in GAMS software version 24.1.3 using a 32-bit laptop with Intel CPU (P6200 2.13GHz) and 2GB RAM with Windows 10. In addition, the results of the sensitivity analysis of input parameters are given in the following sub-sections. Moreover, the results of the final solution of the model in GAMS software are presented and the analyses are performed. For coding the model in GAMS software, the inputs of the sets include the values of parameters related to four projects, five human resources, four machines, three types of raw materials, four time periods, four work activities, eight risk factors and eight risk response strategies.

After solving the model in GAMS software, the outputs include the values of the variables defined in the problem and the values of the objective function. In the proposed model, two variables x_{jt} (binary variable that is 1 if project "j" is selected for investment in time period "t" and otherwise it is zero) and variable z_{jar} (binary variable that it is 1 if response strategy "a" is used for risk incident "r" and in project "j" and otherwise it is zero) were defined. Table 8 presents the outputs of variable x_{jt}. For all three time periods, the first project is selected for investment, where minimizing costs and maximizing profits are both at the appropriate level. Regarding the interaction among strategies, the third strategy has been identified as a constructive and appropriate strategy.

Table 8. The outputs of variable x_{jt}

		Values & Results		
		objfunc1	objfunc2	The relationship
Variable x_{jt}	X(1,1)	-45	-1622	(.LO, .L, .UP, .M = 0, 0, 1, 0)
	X(1,2)	-30	-1575	(.LO, .L, .UP, .M = 0, 0, 1, 0)
	X(1,3)	-50	-1350	(.LO, .L, .UP, .M = 0, 0, 1, 0)

variable Xjt is binary variable that is 1 if project j is selected for investment in time period t and otherwise it is zero

Table 9 presents the outputs of variable z_{jar}. According to Table 9, response strategy 1 has been selected for risk factor 1 in all projects. Regarding the interaction between strategies, the third strategy has been identified as a constructive and appropriate strategy. Negative sign of the values of the functions means the improvement achieved in the values. For example, the maximized profit rate after applying the strategy of response 1 for risk 1 and in project 1 has improved 13 monetary units, for the second project has improved 11 units and for the third project has improved 9 units. Additionally; cost minimization after applying response strategy 1 for risk 1 in all three projects has improved 20 monetary units.

Table 9. The outputs of variable z_{jar}

		Values & Results		
		objfunc1	objfunc2	The Relationship between strategies
Variable z_{jar}	Z(1,1,1)	-13	-20	(.LO, .L, .UP, .M = 0, 0, 1, 0)
	Z(1,1,2)	-11	-20	(.LO, .L, .UP, .M = 0, 0, 1, 0)
	Z(1,1,3)	-9	-20	(.LO, .L, .UP, .M = 0, 0, 1, 0)

variable Zjar is binary variable that it is 1 if response strategy a is used for risk incident r and in project j and otherwise it is zero

Also, the computational CPU time of the model was 0: 00: 00: 015, which is considered a good solution time and therefore, the proposed model managed to select the optimal risk response strategies for the case study.

CONCLUSION

In recent years, project portfolio risk management has attracted much more attention in the scientific and practical fields, while very few analytical tools have been devoted to it. The project portfolio is a means of transferring the strategic needs of the organization to the projects and operational activities. As a result, the risks of the project portfolio can affect the success of the project portfolio and the achievement of strategic goals. Given the important role of project portfolio risk management in the success of an organization, no method has been provided for portfolio-level risk analysis that considers all the elements of the project portfolio and the types of relationships among them.

This study sought to fill the existing research gap by providing a new fuzzy expert system for project portfolio risk management as an urgent practical need.

This research was conducted with the aim of designing a new fuzzy expert system for project portfolio risk management in one of the large construction companies in Iran. For this purpose, first, the risks were gathered through library research and expert judgment for four ongoing projects of this holding. Then, the relationships among risk factors were identified using the developed DEMATEL method. Subsequently, the AHP and fuzzy FMEA methods were used to evaluate the most important risks. In the last step, a fuzzy multi-objective mathematical programming model was developed and solved using the GAMS software to obtain the optimal response strategies to the important risk factors. Twenty-three risk factors were identified in the ongoing projects of the holding under study and 8 risks were recognized as the most important risk factors including: the risk of information system failure, the risk of laws, regulations and warranties, the risk of procurement and distribution costs, the procurement risk, the human resource risk, the technical risk, the safety risk and the supply performance risk. Then, these main risk factors were ranked using the AHP method. The rankings of the main risk factors were obtained using the FMEA method as follows: the risk of information system failure, the risk of laws, regulations and warranties, the risk of procurement and distribution costs, the procurement risk, the human resource risk, the technical risk, the safety risk and the supply performance risk. The results of the proposed fuzzy multi-objective mathematical programming model showed that the model has the efficiency and capability for selecting optimal risk response strategies. Therefore, the proposed fuzzy expert system is able to manage the risks of project portfolio in the case study.

The difficulties in access to the experts and removing the bias from the experts' opinions can be mentioned as the most considerable research limitations.

For future research, the proposed mathematical programming model should be applied to other cases. Also, it is suggested that uncertainty and environmental issues be addressed in the proposed model and the problem be solved with meta-heuristic algorithms. Moreover, minimizing the variance of project profits can be considered as an objective function. The variance of the profit of the projects is equal to the variance of the total net profit of the selected projects. Given the risks affecting project profits, the net profit of each project is a random variable; Therefore, the variance of the project portfolio can be expressed as the variance of a sum of several random variables. Furthermore, other methods-such as system dynamics-may be applied to analyze the relationships among risks.

REFERENCES

Badri, A., Gbodossou, A., and Nadeau, S. (2012). "Occupational health and safety risks: Towards the integration into project management". Safety Science, 50 (2), 190-198.

Bagherian, S. (2015). "Methodology design of portfolio risk management system". Master Thesis in Industrial Engineering, Sharif University of Technology, Faculty of Industrial Engineering. Tehran, Iran.

Bagui, S. K., and Ghosh, A. (2011). "Risk analysis for a BOT project". Jordan Journal of Civil Engineering, 5 (3), 330-342.

Becker, K., and Smidt, M. (2016). "A risk perspective on human resource management: A review and directions for future research". Human Resource Management Review, 26 (2), 149-165.

Ben, B., YanFan, N., Xiao, H., and Xue, B. (2012). "Bacterial foraging-based approaches to portfolio optimization with liquidity risk". Neurocomputing, 98, 90-100.

Charwand, M., Gitizadeh, M., and Siano, P. (2017). "A new active portfolio risk management for an electricity retailer based on a drawdown risk preference". Energy, 118, 387-398.

Chopra, S., and Sodhi, M. S. (2004). "Managing risk to avoid supply-chain breakdown". MIT Sloan Management Review, 53, 61-71.

Esmaeilzadeh, A. (2011). "Risk classification of construction projects and analysis of them using structural equation modeling and Grey approach". MSc Thesis. Allameh Tabataba'i University, Tehran.

Fattahi, R., and Khalilzadeh, M. (2018). “Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA and AHP methods under fuzzy environment”. Safety Science, 102, 290-300.

Finch, P. (2004). “Supply chain risk management”. Supply Chain Management: An International Journal, 9 (2), 183-196.

Gampert, M., and Madlener, R. (2011). “Pan-European management of electricity portfolios: Risks and opportunities of contract bundling”. Energy Policy, 39 (5), 2855-2865.

Ghalia, T., Fidrmuc, J., Samargandi, N., and Sohag, K. (2019). “Institutional quality, political risk and tourism”. Tourism Management Perspectives, 32, 100576.

Ghasemi, F., Sari, M. H. M., Yousefi, V., Falsafi, R., and Tamošaitienė, J. (2018). “Project portfolio risk identification and analysis considering project risk interactions and using Bayesian networks”. Sustainability, 10 (5), 1609.

Ghorbel, A., and Trabelsi, A. (2014). “Energy portfolio risk management using time-varying extreme value Copula methods”. Economic Modeling, 38, 470-485.

Hemmati, M., and Rasoulpour, B. (2014). “Providing a combined algorithm of fuzzy breakpoint analysis and class weighting technique to identify and prioritize project hazards: Case study on a gas supply project”. Standard and Quality Management, 4 (13), 56-67.

Hwee, H.H., and Poon, H.C. (2013). “Risk assessment scenario of Machap dam overtopping using new PMP Malaysian series”. Jordan Journal of Civil Engineering, 7 (1), 9-10.

Ismah Hashim, N., and Chileshe, N. (2012). "Major challenges in managing multiple project environments (MPEs) in Australia's construction industry". Journal of Engineering, Design and Technology, 10 (1), 72-92.

Karmakar, M., and Paul, S. (2019). “Intraday portfolio risk management using VaR and CVaR: A CGARCH-EVT-Copula approach”. International Journal of Forecasting, 35 (2), 699-709.

Khaksari, M., Shafei, R., and Allah Visi, B. (2009). “Recognition the risk roots in constructional projects and the methods of their management: A case study”. Journal of Productivity Management, 2 (7), 139-160.

Khalilzadeh, M., Balafshan, R., and Hafezalkotob, A. (2020). "Multi-objective mathematical model based on fuzzy hybrid multi-criteria decision-making and FMEA approach for the risks of oil and gas projects". Journal of Engineering, Design and Technology, 18 (6), 1997-2016.

Khalilzadeh, M., Shakeri, H., and Zohrehvandi, S. (2021). “Risk identification and assessment with the fuzzy DEMATEL-ANP method in oil and gas projects under uncertainty”. Procedia-Computer Science, 181, 277-284.

Khan, F., Rathnayaka, S., and Ahmed, S. (2015). “Methods and models in process safety and risk management: Past, present and future”. Process Safety and Environmental Protection, 98, 116-147.

Kumar, R.L., and Park, S. (2019). “A portfolio approach to supply chain risk management”. Decision Sciences, 50 (2), 210-244.

Lee, E., Park, Y., and Shin, J.G. (2009). “Large engineering project risk management using a Bayesian belief network”. Expert Systems with Applications, 36 (3-2), 5880-5887.

Mensi, W., Hammoudeh, S.H., and HoonKang, S. (2015). “Precious metals, cereal, oil and stock market linkages and portfolio risk management: Evidence from Saudi Arabia”. Economic Modelling, 51, 340-358.

Micán, C., Fernandes, G., Araújo, M., and Ares, E. (2019). “Operational risk categorization in project-based organizations: A theoretical perspective from a project portfolio risk lens”. Procedia-Manufacturing, 41, 771-778.

Mokhtari, Gh., and Hasanzadeh, Y. (2019). “An integrated multi-objective model for project portfolio selection and risk response actions’ planning.” Journal of Industrial Management Perspective, 8 (4), 9-32.

Mostafaeipour, A., Qolipour, M., and Eslami, H. (2017). “Implementing fuzzy rank function model for a new supply chain risk management’. Journal of Supercomputing, 73, 3586-3602.

Mujalli, R. O. (2018). “Modeling risk of road crashes using aggregated data”. Jordan Journal of Civil Engineering, 12 (1), 45-60.

Nabizadeh, M., Khalilzadeh, M., Ebrahimnejad, S., and Ershadi, M.J. (2021). "Developing a fuzzy goal programming model for health, safety and environment risks based on hybrid fuzzy FMEA-VIKOR method". Journal of Engineering, Design and Technology, 19 (2), 317-338.

Nason, R. (2011). “Market risk management and common elements with credit risk management”. Enterprise Risk Management.

Nazari, A., and Jaberi, M. (2015). “Risk identification in project-based organizations using RBS approach”. International Journal of Industrial Engineering & Production Management, 26 (1), 1-15.

Olfat, L., Khosravani, F., and Jalali, R. (2010). “Identification and ranking of project risk based on PMBOK standard by fuzzy approach”. Journal of Industrial Management Studies, 8 (19), 147-163.

Onyiriu, L. (2016). “Bank assets portfolio structure and risk management in developing economies”. (1st edn.), Bank Risk Management in Developing Economies, Elsevier.

Polak, G.G., Rogers, D.F., and Sweeney, D.J. (2010). “Risk management strategies *via* minimax portfolio optimization”. European Journal of Operational Research, 207 (1), 409-419.

Poursadegh, N., Farshchi, M.R., and Movahedi, M.R. (2013). “Risk management in military contexts: A game-based assessment approach”. Military Management, 13 (51), 1-44.

Project Management Institute. (2017). “A guide to the project management of body of knowledge (PMBOK)”. (6th edn.), Pennsylvania, PA, USA: Project Management Institute.

Qing, L.I., Rengkui, L.I.U., Jun, Z., and Quanxin, S.U.N. (2014). “Quality risk management model for railway construction projects”. Procedia-Engineering, 84, 195-203.

Rabbani, M., Bajestani, M.A., and Khoshkhou, G.B. (2010). “A multi-objective particle swarm optimization for project selection problem”. Expert Systems with Applications, 37 (1), 315-321.

Razi, F.F., Eshlaghy, A.T., Nazemi, J., Alborzi, M., and Poorebrahimi, A. (2015). “A hybrid Grey-based fuzzy C-means and multiple objective genetic algorithms for project portfolio selection”. International Journal of Industrial and Systems Engineering, 21 (2), 154-179.

Ryals, L. (2003). “Making customers pay: Measuring and managing customer risk and returns”. Journal of Strategic Marketing, 11 (3), 165-175.

Soofifard, R., and Khakzar Bafruei, M. (2016). “An optimal model for project risk response portfolio selection (PRRPS) (Case study: Research institute of petroleum industry”. Iranian Journal of Management Studies (IJMS), 9 (4), 741-765.

Teller, J., and Kock, A. (2013). “An empirical investigation on how portfolio risk management influences project portfolio success”. International Journal of Project Management, 31 (6), 817-829.

Unger, B.N., Gemünden, H.G., and Aubry, M. (2012). “The three roles of a project portfolio management office: Their impact on portfolio management execution and success”. International Journal of Project Management, 30 (5), 608-620.

Zamani, A., Khanzadi, M., Jabal Ameli, M., and Sarhadi, M. (2017). “Developing a framework for applying risk management in a fuzzy environment for implementing construction projects value engineering: Case of Khorramshahr Port”. Management Research in Iran, 21 (3), 139-166.

Zhang, Y., and Guan, X. (2018). “Selecting project risk preventive and protective strategies based on bow-tie analysis”. Journal of Management in Engineering, 34 (3), 04018009.