Identifying and prioritizing delay factors in Iran's oil construction projects

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Abstract

Purpose – Successful implementation of construction projects is one of the crucial factors for the economic development of every country. The main part of the countries' capital is allocated to civil and infrastructure projects annually, most of which are accomplished with delay. Construction projects are often criticized for overrunning time and budgets. Analyzing the factors causing delay is essential for omitting them and timely implementation of these projects. Due to the importance of oil projects, this study aims to investigate and analyze the factors causing a delay in Iran's oil construction projects.

Design/methodology/approach – In this research, after a broad literature review, using the fuzzy Delphi method, a total of 75 delay factors were identified under 11 major categories of owner, contractor, consultant, equipment, labor, materials, design, contract and contractual relations, laws and regulations, environmental factors, and managerial factors. Then, by using the best-worst method, the factors were prioritized.

Findings – The results showed that sanction, governmental management systems, weak project management by the contractor, technical and managerial weaknesses of the consultant, financial problems and delay in payment by the owner, low efficiency of the equipment, low productivity of the workforce, changes in laws and regulations, inappropriate organizational structure linking to the project, changes in the design, and changes in the price of materials are the most crucial factors causing a delay in Iran's oil construction projects.

Research limitations/implications – These findings are expected to have significant contributions to Iran's oil construction industry in controlling the time overruns in construction contracts.

Originality/value – The main contribution of this study is to develop a comprehensive framework in which, causes of delay in Iran's oil construction projects are addressed and prioritized.

Keywords Project management, Decision-making, Construction, Fuzzy Delphi method, Multi-criteria decision-making, Delay factors, Best-worst method, Construction projects

Paper type Research paper

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1. Introduction

A construction project is generally considered successful if it is completed on time, within a budget, according to the specifications and stakeholder satisfaction. However, most of the projects are not completed at the expected time. Instead, they are completed before or after the schedule due to many variables and unpredictable factors such as the performance of parties, availability of resources, environmental conditions and contractual relations (Assaf and Al-Hejji, 2006). Delay is considered as one of the most common problems causing negative effects on construction projects and its participating parties and is often responsible for turning profitable projects into failed ventures. These delays can be avoided or reduced if the major delay factors can be identified and handled in a timely manner (Sweis *et al.*, 2008).

Energy resources in Iran are the third-largest oil reserves and the second-largest natural gas reserves in the world. Iran is the most active in the oil and gas sector, accounting for more than 70% of the country's total project value, while most oil and gas projects are behind schedule (Fallahnejad, 2013; Zarei *et al.*, 2017; Sweis *et al.*, 2018b).

Complex and multi-disciplinary, large size, huge investment, long time duration, small key players in the sector, the advanced technologies being used, massive interface, special abilities and complex engineering efforts characterize the uniqueness of oil and gas projects. Managing such projects refers to the unique requirements of managing science, technology and engineering aspects (Mohammad and Price, 2005; Salama, 2008; Sweis *et al.*, 2018a, 2018b).

The success of construction projects in general and oil and gas projects in particular depend on identifying and defining the affecting delay factors of the project. Developing proper strategies and plans is useful to avoid any possible risk to the cost, schedule and quality of the project. These results can help management and the project team to plan for suitable solutions to mitigate the delay factors according to the priority of occurrence and the significance (Kassem *et al.*, 2019).

While the factors causing a delay in construction projects have been widely studied, there are few studies in Iran's oil context, and a comprehensive study in this field is still hard to find. There are some similarities shared with construction projects; however, the factors determined in the literature as causes of delay in construction projects might not apply to oil projects. In addition, the most important causes of delays vary from one country to another. To cover this knowledge gap, the current research attempts to address the following objectives:

- to identify causes of delay in oil construction projects in Iran;
- to prioritize causes of delay in oil construction projects in Iran.

For this purpose, causes of delay in the oil construction of Iran are identified using the fuzzy Delphi method (FDM) and prioritized using the best-worst method (BWM). Indeed, this study proposes a process integrating FDM and BWM to engage the challenge of identification and prioritizing of delay factors in oil construction projects. The FDM effectively gathers the opinion of experts toward developing critical delay factors and meanwhile reduces the ambiguity and uncertainty existing in experts' judgments. The BWM is used to construct a structure to prioritize the selected delay factors previously identified by the FDM.

The work is structured as follows: a literature review is presented in the next section. Then research methodology is given. Afterward, findings are presented. The final section concludes the paper.

2. Literature review

Delay in construction projects has been attracting much attention among researchers for decades and various aspects of delay in construction projects have been studied.

As discussed by Mohammad and Price (2005), there is a considerable similarity between the construction phase of oil and gas projects and general construction projects. However, in this section, we review the literature in two parts: a general perspective, and oil and gas projects.

2.1 Causes of delay in construction projects: a general perspective

Abbasi *et al.* (2020) investigated the causes of delays in the construction industry of Iran using a cause-and-effect diagram. Causes of delays were classified into eight main groups including the contractor, owner, design, procurement, equipment, consultant, labor, and miscellaneous. Results showed that the financial problems of the contractor were the main factors causing the delay. Delay causes of construction projects for developing Southeast Asia countries were explored by Wuala and Rarasati (2020). Base on the findings, contractor- and owner- related causes were the most crucial factors causing a delay in these countries. Al-Maktoumi *et al.* (2020) assessed the causes of delays in construction projects in Oman. They reported that the owner-, equipment- and material-related factors had a considerable impact on the delay of projects. Latif *et al.* (2019) also reported that changes in the scope of the project, lack of communication between parties and shortage of skilled labor were three top delay factors in Oman.

Following a statistical survey, Muneeswaran *et al.* (2020) analyzed the causes of delay in the Indian construction industry. An inadequate schedule was found to be the most critical factor. Razi *et al.* (2019) investigated delay causes of a road construction project in Malaysia using the analytic hierarchy process (AHP) technique. Fund risk, flood, heavy rain, unforeseen ground condition and existing utility issue were determined as the most prioritized factors. Based on a questionnaire survey, Kog (2019) reported construction delays in Indonesia, Malaysia, Thailand and Vietnam. It was revealed that most of the delay factors in Indonesia and Malaysia were linked with contractors. While contractor- and owner-related factors were top delay factors in Thailand. As stated by Prasad *et al.* (2019), finance-related causes were the most critical causes of delay in Indian projects. Following a questionnaire survey, Alsuliman (2019) ranked the causes of delay in Saudi public construction projects. Awarding tenders group was identified as the first group affecting delay. Using a hybrid fuzzy TOPSIS [1] – BWM, Norouzi and Ghayur-Namin (2019) investigated and prioritized causes of delay in a railway megaproject in Iran. Inability to meet the project required standards, inappropriate planning and scheduling and defective design were identified as the ones with the highest priority.

Hosaini and Singla (2019) determined and ranked causes of delay in construction projects in Afghanistan. The top three delay causes were ineffective planning and scheduling of a project by the contractor, delay in progress payments by owner, and poor site management and supervision of contractors by consultant and owner. Based on a questionnaire survey, Sweis *et al.* (2018a) introduced the delay factors of strategic industrial projects in Iran. The most critical factors were sanctions, cash flow problems, equipment availability and failure, project manager competence, material procurement, and unqualified labor. Al-Hazim *et al.* (2017) investigated factors causing completion delay and cost overrun in infrastructure projects in Jordan. The findings showed that terrain and weather conditions were the main factors causing the delay. Gebrehiwet and Luo (2017) analyzed the causes of delay at different stages of construction in Ethiopian construction projects. As a result, the five most important causes of delay were identified as corruption, unavailability of utilities at site, inflation or price increases in materials, lack of quality materials, and late approval of design documents.

Following a questionnaire survey, Oyegoke and Kiyumi (2017) provided causes of delay in megaprojects in the Sultanate of Oman. The five most frequent causes of delay were selection of the lowest bid by the owner, financial condition of the main contractor, delay in decision-making by the owner, poor construction planning by the contractor, and changes in design by the owner. Delay causes of road construction projects in Egypt were explored by Aziz and Abdel-Hakam (2016). A questionnaire and personal interviews listing 293 delay causes formed the basis of the paper. Poor site management and supervision by the contractor was reported as the most crucial factor. Marzouk and El-Rasas (2014) analyzed delay causes in Egyptian construction projects. The feedback of construction experts was obtained through interviews and questionnaire surveys. The top Five delay causes were late payments for completed work, changes of order and scope by the owner, effects of subsurface conditions, the low productivity level of laborers, and ineffective planning and scheduling of the project.

Abbasnejad and Izadi-Moud (2013) identified construction delay factors in Iranian civil engineering projects. They concluded that the most crucial factor is the lack of knowledge of the involved members of the projects about the nature of the construction industry. Aziz (2013) described various numerous factors delay in construction projects in Egypt. In total, 99 factors were short-listed to make part of the questionnaire survey and were identified and categorized into nine significant categories consisting of consultant, contractor, design, equipment, external, labor, materials, owner, and project-related factors. Based on a questionnaire survey and using structural equation modeling, Doloi *et al.* (2012) investigated factors affecting delay in Indian construction projects. The findings highlighted the importance of the role of owner and technical expertise in planning to decrease time delays. Reasons for delay in Iranian construction projects were studied by Koshgoftar *et al.* (2010). Finance and payments of completed work were identified as the most important causes of the delay.

Investigating the factors causing a delay in Saudi Arabian public sector, Kharashi *et al.* (2009) reported that the lack of qualified and experienced personnel and associated current undersupply of labor were the most influencing causes of delay. Toor and Ogunlana (2008) analyzed the leading causes of delays in Thailand construction projects. Factors related to designers, contractors and consultants were rated among the top problems. Sweis *et al.* (2008) identified and classified the causes of construction delay in residential projects in Jordan. Financial difficulties faced by the contractor, and too many change orders by the owner were determined as the leading causes of construction delay. Investigating causes of delay in Vietnam large construction projects, Le-Hoai *et al.* (2008) reported poor site management and supervision, poor project management assistance, financial difficulties of the owner and contractor, and design changes as the five most critical causes. Based on a survey by Faridi *et al.* (2006), it was reported that approval of drawings, inadequate early planning and slow decision-making by the owner were the top causes of delay in the UEA construction industry. A questionnaire survey was conducted by Sambasivan and Soon (2007) to identify the causes and effects of delay in the Malaysian construction industry from the owners', consultants' and contractors' view. The five most important causes were contractor's improper planning, poor site management and inadequate experience, inadequate owner's finance and payments for completed work, and problems with subcontractors.

Adopting a questionnaire survey approach for understanding the risks in Indonesian construction projects, Andi (2006) identified 27 construction risks. A survey on the time performance of different types of construction projects in Saudi Arabia was conducted by Assaf and Al-Hejji (2006) to determine the causes of delay and their importance in the view

of the project participants consisting of the owner, consultant and contractor. The most critical causes of delay in Jordanian construction projects with traditional type contracts from the viewpoint of construction, contractors and consultants were introduced by Odeh and Battaineh (2001). The results indicated that owner interference, inadequate contractor experience, financing and payments, labor productivity, slow decision-making, improper planning, and subcontractors were among the top critical factors. Supporting the finding by Al-khalil and Al-Ghafly (1999), lack of agreement among the parties was one of the root causes of delay of construction projects in the Eastern Province of Saudi Arabia. Based on a survey by Mezher and Tawil (1998), 64 causes of delay in Lebanon construction projects were identified. It was found that owners, consultants and architectural/engineering firms generally agreed on the ranking of the significant categories of delay factors. Zakeri *et al.* (1996) surveyed Iranian construction operative productivity. Materials shortage, weather and site conditions, equipment breakdown, drawing deficiencies/change orders, and lack of proper tools and equipment were identified as the most problems.

2.2 Causes of delayed construction projects: oil and gas projects

Supporting the findings by Aljamee *et al.* (2020), contractor due to using the lowest bidding prices was the main reason for the delay in construction projects in the Iraqi petroleum and gas industry. Causes of delay in an oil and gas engineering, procurement and construction (EPC) project in Indonesia were studied by Hatmoko and Khasani (2019). They concluded that the financial capability of contractors significantly influenced the EPC project, with an estimated delay of 33% of the total project duration. Based on a survey by Kassem *et al.* (2019), internal risks, followed by changes during a construction project, government instability, incorrect project cost estimation, government delay in decision-making, incorrect project schedule estimation and political situation, and war were the greatest influential factors in construction projects in the Yemen oil and gas sector. Gomarn and Pongpeng (2018) investigated construction delays caused by contractors and suppliers in Thailand's oil and gas platform projects. The most critical factors were poor site management and supervision by contractors, and the supply of unqualified and unskilled personnel by suppliers.

As stated by Abdullah *et al.* (2018), delays in subcontractor's work, lack of subcontractor skill, and poor planning and scheduling were the most crucial factors causing a delay in Palm oil refinery construction projects in Malaysia. Sweis *et al.* (2018b) reported causes of delay in Iran's oil and gas projects using root cause analysis and under five categories consisting of financial-, operational-, site-, human and equipment- and external- related. The operational-related category was identified as the most effective category. Suppramaniam *et al.* (2018) reviewed and categorized causes of delay in Malaysian construction oil and gas projects in six major categories, namely, owner, contractor, engineering, external, project, and resources. Zarei *et al.* (2017) analyzed the causes of delay in the complex construction project in the oil-gas-petrochemical sector in Iran using a semantic network analysis approach. Results showed that the main factor causing delay was initial negotiation deficiencies.

Causes of delay in construction projects in the oil and gas industry of the Persian Gulf cooperation council countries were investigated by Ruqaishi and Bashir (2014). Seven factors consisting of poor site management and supervision by contractors, problems with subcontractors, inadequate planning and scheduling of projects by contractors, poor management of contractors' schedules, delay in delivery of materials, lack of effective communication among the project stakeholders, and poor interaction with vendors in the engineering and procurement stages were revealed as the significant causes of project delay.

Leading causes of delay in the projects of zone 3 of Iranian Gas Transmission Company were analyzed by Atafar and Eghbali (2013). For this purpose, some experts were interviewed. The results suggested a failure to fulfill obligations by the contractor as the most critical factor. Adapting a multiple case study, Pham and Hadikusumo (2014) identified factors affecting delays in EPC petrochemical projects in Vietnam. Fallahnejad (2013) determined and ranked causes of delay in 24 gas pipeline projects in Iran. The 10 major delay factors were imported materials, unrealistic project duration, materials to be supplied by owner, land expropriation, change orders, contractor selection methods, payment to the contractor, obtaining permits, suppliers and contractor's cash flow.

Ravand and Salai (2011) examined the causes of delay in the implementation of oil and gas industrial projects in Iran. The most crucial factors were weaknesses in primary studies, lack of expert labor, lack of timely funding and contractual ambiguities. Following an interview-based questionnaire Salama *et al.* (2008) investigated the factors leading to time overruns in the oil and gas projects in the United Arab Emirates (UAE). The five most important causes were delay in the start of purchasing long-lead items, delay in materials and equipment delivery, lack of experience and knowledge of contractor technical staff, poor project management by contractor, and shortage of experienced and qualified engineers. Thuyet *et al.* (2007) identified the main causes of delays in oil and gas construction projects in Vietnam. The major causes of delay were bureaucratic government system and long project approval procedures, poor design, incompetence of project team, inadequate tendering practices, and late internal approval processes from the owner.

The literature review revealed that albeit considerable research has been conducted to investigate the affecting delay factors in the construction industry worldwide, only a few research has concentrated on the delay factors in oil and gas construction projects. Moreover, few studies have investigated this issue in Iran. Therefore, the current research aimed to study the causes of delays in oil construction projects in Iran.

Based on the literature review, Table 1 shows causes of delay in construction projects under 10 categories namely, owner, contractor, consultant, equipment, labor, materials, design, contract and contractual relations, laws and regulations, and environmental factors. The frequency of each factor in the literature can be seen in column 3.

3. Research approach

The research was conducted in three stages. Figure 1 shows the procedure for doing this research. In the first step, previous research studies were studied and reviewed, and delay factors in construction projects were categorized in different categories. In the second step, FDM was used to identify the delay factors in Iran's oil construction projects. In this regard, a questionnaire survey approach was adopted to find the main factors affecting delay in Iran's oil construction projects. After identifying the delay factors, they were prioritized by using BWM. For this purpose, another questionnaire was prepared for getting the opinion of the experts. Details of FDM and BWM are described below:

3.1 Fuzzy Delphi method

The Delphi method is based on the philosophical assumption that "n heads are better than one." It is a procedure designed to sample a group to gain the opinion of knowledgeable persons on a particular topic (Fish and Busby, 1996). The traditional Delphi method has apparent weaknesses; it is costly, time-consuming and has a lower questionnaire return rate as it tries to lead to converged results by repetitive surveys. Furthermore, the problems of uncertainty and ambiguity again exist in experts' responses (Shen *et al.*, 2010). To overcome these shortcomings, some studies have proposed specific optimized methods; the most

Category	Delay factor	Frequency
1. Owner	Financial problems and delay in payment	39
	Slowness in decision-making and administrative bureaucracy	36
	Unrealistic contract duration	20
	Delay in site delivery	19
	Types of biding and rewards	13
	Delay in reviewing and approving documents	14
	Owner interference	11
	Poor communication and coordination with other parties	11
	Ineffective incentives and penalties	9
	Lack of experience	8
	Inappropriate feasibility study of the project	5
	Delay in materials to be supplied by the owner	5
	Frequent change of managers	2
2. Contractor	Problems with subcontractors	34
	Financial problems	31
	Inadequate experience	30
	Ineffective project planning and scheduling	29
	Poor site management and supervision	28
	Inappropriate construction methods	19
	Rework to correct undesirable work	18
	Poor communication and coordination with other parties	15
	Poor qualification of the contractors' technical staff	14
	Weak project management	4
	Improper pricing by contractors to win the bid	5
3. Consultant	Delay in reviewing and approving the design, drawings and ...	21
	Delay in conducting inspection and testing	17
	Inadequate experience	15
	Weak communication and coordination with other parties	10
	Poor contract management	8
	Quality assurance/control	9
	Ambiguities and mistakes in specifications, drawings or documents	6
	Technical and managerial weaknesses	2
4. Equipment	Shortage of equipment	26
	Frequent failure of equipment	21
	Low efficiency of the equipment	15
	Lack of high-tech mechanical equipment	7
	Slow mobilization of equipment	4
	Inappropriate selection of equipment and faulty equipment	2
5. Labor	Shortage of labor	32
	Low productivity	32
	Low motivation	6
	Nationality	3
	Personal differences between employees	1
6. Materials	Delay in delivery of materials	35
	Shortage of materials	31
	Changes in price	18
	Low quality	15
	Changes in the type and characteristics of materials	13
	Damage of stored materials	9
	Problems with providing materials at current official prices	1

(*continued*)

Table 1.
Delay factors in construction projects

Category	Delay factor	Frequency
7. Design	Changes in design	12
	Mistakes and discrepancies in design documents	11
	Poor use of advanced engineering design software	4
	Misunderstanding of owner requirements by the design engineer	3
	Incomplete/conflicts of design drawings details and specifications	4
8. Contract and contractual relations	Changes in orders of contract	11
	Lack of communication between the parties	10
	Major disputes and negotiations	8
	Inappropriate organizational structure linking to the project	7
	Mistakes and disputes in the contract documents	6
9. Laws and regulations	Changes in laws and regulations	20
	Tax laws, tariffs and customs duties	3
	Weaknesses in the laws and regulations	2
10. Environmental factors	Weather conditions	22
	Unexpected geological conditions	18
	Inflation	12
	Incidental events such as flood, earthquake, and storm	10
	Economic changes such as changes in the exchange rate	8
	Problem with neighbors	8
	Change in government policies	3
	Sanction	2

Table 1.

representative of them is the FDM developed by Murray *et al.* (1985), which combines the fuzzy theory and the Delphi method. The FDM can converge experts' responses with fewer survey rounds and constructively conduct their uncertainty and ambiguity. In FDM, the experts' judgments are represented by fuzzy numbers. Then the subjective opinions are transformed into objective data through a fuzzy operation.

Project risks and delay factors have an uncertain nature, and assigning precise crisp numbers to them is not a suitable way. Fuzzy logic is quite appropriate for the task of considering the uncertain nature of risks and delay factors in construction projects based on experience and managerial subjective judgment (Tavakolan and Etemadinia, 2017). Therefore, we used FDM to obtain the delay factors for Iran's oil construction projects. The procedure of FDM used in this study is as follows:

Step 1: Collect the opinions of experts: A questionnaire was prepared for getting the opinion of 10 experts of the National Iranian Oil Engineering and Construction Company (NIOEC). Note that NIOEC is responsible for the implementation of Iran's infrastructure projects in the field of petroleum refining, petroleum pipelines and depots, as well as joint venture overseas petroleum-related projects. Some of the accomplished projects are as below:

- Construction of Arak refinery.
- Construction of Bandar Abbas refinery.
- Installation of more than 5,000 km crude oil and oil products pipelines.
- Installation of more than 170 pump stations.
- Installation of more than 10 oil terminals and storage tanks.

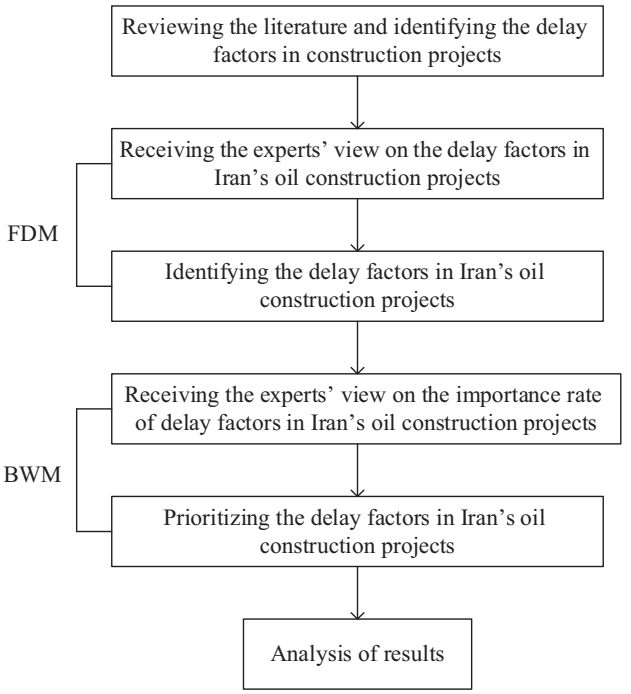

Figure 1. The procedure of doing this research

It is also to be mentioned that all respondents were experts with 10 to 30 years of experience in different areas of oil projects such as project management and engineering. The judgment of every expert on the delay factors was obtained using the semantic variables included in the questionnaire. We accordingly set fuzzy linguistic scale and triangular fuzzy numbers as shown in Table 2.

Step 2: Calculate the evaluation values of every delay factor according to the triangular fuzzy number: Let $w_{ik} = (a_{ik}, b_{ik}, c_{ik})$ denotes the evaluation value of the delay factor $k \in N\{1,\ldots n\}$ given expert $i \in M\{1,\ldots m\}$. Then the fuzzy weight of the delay factor k is defined as:

$$w_k = (\alpha_k, \beta_k, \gamma_k), \quad k = 1, 2, \ldots, n \tag{1}$$

where $\alpha_k = \min_{i \in N} a_{ik}$, $\beta_k = \frac{1}{m}\sum_{i=1}^{m} b_{ik}$ and $\gamma_k = \max_{i \in N} c_{ik}$.

Fuzzy linguistic scale	Evaluation linguistic term set	Triangular fuzzy numbers (a,b,c)
$\tilde{9}$	Very important	(7,9,9)
$\tilde{7}$	Important	(5,7,9)
$\tilde{5}$	Moderate	(3,5,7)
$\tilde{3}$	Unimportant	(1,3,5)
$\tilde{1}$	Very unimportant	(1,1,3)

Source: (Shen *et al.*, 2010)

Table 2. Evaluation of the linguistic term set and the corresponding triangular fuzzy numbers

Step 3: Defuzzification: To obtain the final weight, S_k, the fuzzy weight of every delay factor is defuzzied using a simple center of the gravity method by equation (2):

$$S_k = \frac{\alpha_k + \beta_k + \gamma_k}{3} \tag{2}$$

Step 4: Set a threshold ρ to select the important delay factors among others: If $S_k > \rho$, the delay factor k is retained; otherwise, the delay factor k is abandoned (Zhang, 2017). Note that the value of the threshold ρ depends on the users' preference (Shen *et al.*, 2010). If users want more delay factors, they can set the threshold small and vice versa. In this study, we set $\rho = 5.5$.

It would be mentioned that a practical consideration facing the researcher is the number of experts their opinions are gathered. There are no hard and fast rules; where the group is homogeneous, then a smaller sample of between 10 to 15 people may yield sufficient results. However, if several groups are involved (e.g. an international study), then a larger sample will likely be needed (Skulmoski *et al.*, 2007).

3.2 Best-worst method

After identifying delay factors in Iran's oil construction projects, we aim to prioritize these factors based on their importance. In this regard, we use BWM. Here, we briefly describe the steps of BWM that can be used to determine the weights of the delay factors (Rezaei, 2016).

Step 1: Determine a set of delay factors. We identified the delay factors using FDM in the previous section. The delay factors set as $\{c_1, c_2, \ldots, c_n\}$.

Step 2: Determine the most important (the best) and the least important (the worst) delay factors in each category by getting the opinion of the experts.

Step 3: Determine the preference of the most important (best) delay factor among the other factors using a number between 1 and 9 and by getting the opinion of the experts. The resulting best-to-others (BO) vector would be:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{3}$$

where a_{Bj} indicates the preference of the most important delay factor B over the delay factor j. It is clear that $a_{BB} = 1$.

Step 4: Determine the preference of all delay factors over the least important (worst) delay factor using a number between 1 and 9 and by getting the opinion of the experts. The resulting others-to-worst (OW) vector would be:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T \tag{4}$$

where a_{jW} indicates the preference of delay factor j over the least important delay factor W. It is clear that $a_{WW} = 1$.

Step 5. Find the optimal weights of each delay factor $(w_1^*, w_2^*, \ldots, w_n^*)$ by solving the following linear programming problem:

$$\begin{aligned} &\text{Min } \xi \\ &s.t: \\ &|w_B - a_{BJ} w_j| \le \xi \ , for\ all\ j \\ &|w_j - a_{jW} w_W| \le \xi \ , for\ all\ j \\ &\sum_j w_j = 1 \\ &w_j \ge 0 \ , for\ all\ j \end{aligned} \tag{5}$$

Problem (5) is a linear program, which has a unique solution. Solving problem (5), the optimal weights, $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^* are obtained. For this model, ξ^* can be considered as an indicator of the consistency of the comparisons. Considering the consistency index (Table 3), the consistency ratio is calculated as follows:

$$Consistency\ Ratio = \frac{\xi^*}{Consistenct\ Index} \tag{6}$$

a_{BW} is the preference of the most important delay factor over the least important delay factor. Consistency ratio $\in$ [0,1], values close to 0 show more consistency, while values close to 1 show less consistency.

4. Findings and discussion

4.1 Identification of the initial delay factors in construction projects

As mentioned above, by an extensive literature review, the initial factors causing a delay in construction projects were identified. These factors were categorized into 10 groups including owner, contractor, consultant, equipment, labor, materials, design, contract and contractual relations, laws and regulations and environmental factors. For each category, the subcategories were also determined (Table 1).

4.2 Implication of fuzzy Delphi method

FDM was adopted to determine the final delay factors in Iran's oil construction projects. To do this, we collected the experts' judgments through a two-round survey. A questionnaire was prepared and sent to the experts of NIOEC to gather their idea about the importance of each delay factor. A list of the possible delay factors in construction projects was presented, and the respondents were asked to rate each factor according to their relative importance as a significant factor (very important, important, moderate, unimportant and very unimportant). Moreover, the experts were asked to add other appropriate and necessary delay factors not specified in the questionnaire. In this round, a new category named managerial factors was added to the list of delay factors.

For the second round, delay factors and their average scores were sent to the experts, and the experts were asked to determine their opinion on the importance of each factor concerning their average scores. Then we used equations (1) and (2) to deal with the data and obtain the values in columns 3 to 6 of Table 4. For instance, if an expert rated the financial problems of the owner as very important, the fuzzy number (7, 9, 9) was assigned to this factor. We gathered the opinions of 10 experts; therefore, we had 10 fuzzy numbers. To combine these opinions, we used equation (1) and to obtain the weight of the factor, equation (2) was applied.

As we chose $\rho = 5.5$, the delay factors with the final score of 5.5 or more were selected as the leading delay factors in Iran's oil construction projects.

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index (Max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Source: (Rezaei, 2016)

Table 3. Consistency index table

Category	Delay factor	Scores Min (α_k)	Mean (β_k)	Max (γ_k)	Final (S_k)
Owner	Financial problems and delay in payment	3	6.6	9	6.2
	Unrealistic contract duration	3	6.6	9	6.2
	Delay in reviewing and approving documents	1	5	9	5
	Slowness in decision-making and administrative bureaucracy	1	4.6	7	4.2
	Poor communication and coordination with other parties	1	4.6	7	4.2
	Delay in site delivery	1	4.6	9	4.9
	Delay in materials to be supplied by the owner	3	6.6	9	6.2
	Owner interference	1	5	9	5
	Types of biding and rewards	3	6.6	9	6.2
	Ineffective incentives and penalties	1	4.6	9	4.9
	Frequent change of managers	1	4.6	9	4.9
	Lack of experience	1	4.6	7	4.1
	Inappropriate feasibility study of the project	3	6.2	9	6.1
Contractor	Financial problems	1	5.8	9	5.3
	Inadequate experience	3	6.6	9	6.2
	Poor site management and supervision	5	7.4	9	7.1
	Rework to correct undesirable work	3	6.2	9	6.1
	Inappropriate construction methods	3	5.4	9	5.8
	Poor communication and coordination with other parties	1	4.6	7	4.2
	Ineffective project planning and scheduling	3	6.2	9	6.1
	Problems with subcontractors	3	5.8	9	5.9
	Weak project management	5	8	9	7
	Poor qualification of the contractors' technical staff	1	5.4	9	5.1
	Improper pricing by contractors to win the bid	3	7.4	9	6.5
Consultant	Weak communication and coordination with other parties	1	4.6	7	4.2
	Inadequate experience	3	6.6	9	6.2
	Delay in conducting inspection and testing	3	6.2	9	6.1
	Delay in reviewing and approving the design, drawings and [. . .]	1	5.4	9	5.1
	Ambiguities and mistakes in specifications and drawings and documents	3	5.8	9	5.9
	Technical and managerial weaknesses	3	6.6	9	6.2
	Poor contract management	3	5.4	9	5.8
	Quality assurance/control	1	3.4	7	3.8
Equipment	Frequent failure of equipment	1	5	9	5
	Shortage of equipment	1	6.2	9	5.4
	Low efficiency of equipment	3	6.2	9	6.1
	Inappropriate selection of equipment and faulty equipment	1	6.2	9	5.4
	Slow mobilization of equipment	1	4.2	7	4.1
	Lack of high-tech mechanical equipment	1	4.6	7	4.2
Labor	Low productivity	5	7.8	9	7.3
	Low motivation	3	7	9	6.3
	Shortage of labor	1	4.2	9	4.7
	Personal differences between employees	1	3	7	3.7
	Nationality	1	3	5	3
Materials	Shortage of materials	1	3.8	7	3.9
	Delay in delivery of materials	1	4.6	9	4.9
	Low quality	1	4.6	9	4.9

(*continued*)

Table 4. Delay factors in Iran's oil construction projects

Category	Delay factor	Scores Min (α_k)	Mean (β_k)	Max (γ_k)	Final (S_k)
	Changes in price	3	7	9	6.3
	Changes in the type and characteristics of materials	1	5	9	5
	Damage of stored materials	1	4.6	9	4.9
	Problems with providing materials at current official prices	1	5.4	9	5.1
Design	Mistakes and discrepancies in design documents	1	4.2	7	4.1
	Incomplete/conflicts of design drawings details and specifications	1	3.8	7	3.9
	Poor use of advanced engineering design software	1	4.6	7	4.2
	Changes in design	3	6.6	9	6.2
	Misunderstanding of owner requirements by the design engineer	3	5	7	5
Contract and contractual relations	Mistakes and disputes in the contract documents	1	4.6	7	4.2
	Changes in orders of contract	1	4.6	7	4.2
	Lack of communication between the parties	1	4.6	7	4.2
	Major disputes and negotiations	1	4.6	7	4.2
	Inappropriate organizational structure linking to the project	3	75.4	9	5.8
Laws and regulations	Changes in laws and regulations	3	6.6	9	6.2
	Weaknesses in the laws and regulations	1	5	9	5
	Tax laws, tariffs and customs duties	1	4.6	9	4.9
Managerial factors	Absence of a real system for managers' performance measurement	5	7.8	9	7.3
	Failure to appoint managers based on their performance evaluation	5	7.4	9	7.1
	Lack of feedback in case of any deviations in time and cost and quality of projects in governmental management systems	5	8.6	9	7.5
Environmental factors	Unexpected geological conditions	1	4.2	9	4.7
	Weather conditions	1	3	7	3.7
	Incidental events such as flood, earthquake, and storm	1	3.4	9	4.5
	Sanction	5	7.8	9	7.3
	Inflation	5	8.2	9	7.4
	Economic changes such as changes in the exchange rate	5	8.6	9	7.5
	Problem with neighbors	1	3.8	7	3.9
	Change in government policies	1	5	9	5

Table 4.

4.3 Implication of best-worst method

After identification of the delay factors in Iran's oil construction projects, these factors were prioritized using BWM. For this purpose, a meeting consisting of the experts was held. The opinion of experts about the best and the worst factors in each category was gathered. Moreover, the preference of the best delay factor among the other factors (A_B), and the preference of all delay factors over the worst delay factor (A_W) were determined. Finally, the optimal weights were obtained by solving the problem (5). Table 5 depicts the results of the implication of BWM.

4.4 Discussion

Findings show that the fundamental group causing delay in oil construction projects are environmental category, followed by managerial factors, consultant, contractor, owner, labor, contract and contractual relations, laws and regulations, equipment, design, and materials.

Category	Delay factor	Weight	Priority	Rate of consistency
Main factors	Environmental factors	0.25	1	0.01
	Managerial factors	0.15	2	
	Consultant	0.1	3	
	Contractor	0.1	3	
	Owner	0.07	4	
	Labor	0.07	4	
	Contract and contractual relations	0.06	5	
	Laws and regulations	0.06	5	
	Equipment	0.06	5	
	Design	0.05	6	
	Materials	0.02	7	
Owner	Financial problems and delay in payment	0.35	1	0.07
	Types of biding and rewards	0.21	2	
	Inappropriate feasibility study of the project	0.21	2	
	Delay in materials to be supplied by the owner	0.14	3	
	Unrealistic contract duration	0.09	4	
Contractor	Weak project management	0.29	1	0.06
	Poor site management and supervision	0.15	2	
	Ineffective project planning and scheduling	0.15	2	
	Improper pricing by contractors to win the bid	0.15	2	
	Inadequate experience	0.07	3	
	Problems with subcontractors	0.07	3	
	Inappropriate construction methods	0.06	4	
	Rework to correct undesirable work	0.06	5	
Consultant	Technical and managerial weaknesses	0.37	1	0.1
	Poor contract management	0.23	2	
	Inadequate experience	0.16	3	
	Ambiguities and mistakes in specifications and drawings and documents	0.16	3	
	Delay in conducting inspection and testing	0.09	4	
Equipment	Low efficiency of the equipment	1	1	
Labor	Low productivity	0.67	1	
	Low motivation	0.37	2	
Materials	Changes in price	1	1	
Design	Changes in design	1	1	
Contract and contractual relations	Inappropriate organizational structure linking to the project	1	1	
Laws and regulations	Changes in laws and regulations	1	1	
Managerial factors	Lack of feedback in case of any deviations in time and cost and quality of projects in governmental management systems	0.64	1	0.06
	Absence of a real system for managers' performance measurement	0.24	2	
	Failure to appoint managers based on their performance evaluation	0.1	3	
Environmental factors	Sanction	0.57	1	0.14
	Economic changes such as changes in the exchange rate	0.29	2	
	Inflation	0.14	3	

Table 5.
Prioritizing the delay factors in Iran's oil construction projects

Environmental factors are the most significant factors causing a delay in Iran's oil construction projects. The environment's influence is found to be due to sanction, economic changes, and inflation. This finding is indeed similar to the findings of Sweis *et al.* (2018a) that identified sanction as one of the most causes of delay in strategic industrial projects in Iran.

Managerial factors are found to be the second most significant factors affecting schedule performance in Iran's oil construction projects. As far as the oil construction projects are managed by governmental systems, there is not any real feedback in case of deviations in time and cost and quality of the projects, managers' performance is not measured carefully and project managers are not evaluated based on their real performance. This finding is a new detection which has not been reported on Iran's construction projects so far.

Among different causes of delay, financial problems and delays in payment by the owner, weak project management by the contractor and technical, and managerial weaknesses of consultants were ranked as the most critical delay causes. Similarly, low efficiency of equipment, low productivity of labor, changes in the price of material, changes in design, inappropriate organizational structure linking to the project, and changes in laws and regulations were identified as other crucial causes of delay in Iran's oil construction projects.

The results of the present study are in close agreement with that of earlier studies in developing countries. Comparison of the results of the study with the previous research indicated that the owner's financial problems were found to be the most critical causes of delay in the oil and gas construction industry of the countries such as Iran and India (Fallahnejad, 2013; Prasad *et al.*, 2019). As stated by Zakeri *et al.* (1996) and Sandhyavitri (2019), changes in design and specifications are one of the significant causes of delays in oil construction projects in Iran and Indonesia. Moreover, our findings are supported by prior research conducted by Zakeri *et al.* (1996) and Ravand and Salai (2011) that low efficiency of equipment and low productivity of labor are critical delay factors in construction projects in Iran. These findings are also consistent with the previous study that ineffective planning and scheduling by the contractor was identified as one of the most three important delay factors in EPC petrochemical projects in Vietnam (Pham and Hadikusumo, 2014). Moreover, poor site management and supervision, and ineffective project planning and scheduling were identified as the main causes of delays in oil and gas construction projects in Oman (Ruqaishi and Bashir, 2014). Policy in bidding tender to the lowest price was identified as one of the five important delay factors in oil construction projects of Malaysia (Abdullah *et al.*, 2018). Furthermore, the most important reason for delays from contractors in construction projects was poor site management and supervision in Thailand's oil and gas platform projects (Gomarn and Pongpeng, 2018). Finally, there is consistency between the current study and Aljamee *et al.* (2020) in terms of ranking types of bidding and rewards and weak project management in the top five most important causes of delay in Iraq's petroleum industry.

Based on the results of this study and other similar works in this area, financial problems are one of the most important problems in oil and gas construction projects. Financial problems of owners lead to problems for contractors such as paying the wages of workers, employees and subcontractors, paying the rent for machinery and equipment, and buying needed materials for the project. Therefore, owners should allocate enough financial resources for the projects before the tender phase. They should pay the contractor based on the schedule and at the right time (Koshgoftar *et al.*, 2010).

Weak project management by the contractor, and technical and managerial weaknesses by the consultant were identified as key delay factors. Hence, owners are supposed to ensure

the employment of competent and qualified personnel. Construction managers should have the necessary experience and qualifications in oil construction and project management. In this way, developing training programs in different sectors of construction will be useful (Rachid, 2018). A high degree of training of employees would reduce the criticality of several problems such as low productivity of labors. Training programs could provide workers with the required techniques and skills concerning scheduling, cost and time control, and risk analysis (Bajjou and Chafi, 2018).

5. Conclusions and recommendations

This study quantitatively investigated the selection and prioritization of causes of delay in Iran's oil construction projects. For this purpose, by reviewing the literature we first identified the delay factors in 10 categories. Then using FDM and by collecting the opinion of Iranian experts in the field of oil project management through a two-round survey, a total of 75 potential delay factors were identified and categorized into 11 groups: owner, contractor, consultant, equipment, labor, materials, design, contract and contractual relations, laws and regulations, managerial factors and environmental factors. In the next step, we used BWM to prioritize the factors and determine the most important ones. The results show that environmental and managerial factors are the most important delay factors in Iran's oil construction projects.

Based on our results, we recommend the followings to minimize and control the delay in Iran's oil construction projects:

- In consideration of financial problems and delays in payment by owners, initial cost estimates should be as accurate as possible. Correct estimation would allow owners to ensure that the required funds for executing the projects are sourced at right time and made available when required.
- Based on weak project management by contractor, only the contractor's financial proposal should not be considered for selecting the contractors; rather, less weight to prices and more weights to the capabilities and past performance of contractors should also be assigned.
- Taking into account the technical and managerial weaknesses of consultants, developing human resources may apply to consultants who usually lack adequate managerial skills.
- Concerning the low efficiency of equipment, advanced equipment should be used in oil construction projects; if not available, it is essential to check the availability of necessary construction equipment.
- Attending to low productivity of laborers, developing human resources in the oil construction industry through proper training should be taken into consideration.
- Addressing changes in the price of materials, price differences could be considered in the contract.
- Regarding changes in design, it should be considered that owners may demand some design changes during construction but to a limit having no adverse effects on the activities on the critical path.
- Considering inappropriate organizational structure linking to the project, the appropriate organizational structure should be linked to the project. There would be specific projects that cannot be managed by certain types of organizational structures. For instance, it is challenging to execute quick impact projects in a

functional organizational structure due to the slow decision-making processes and bureaucracies associated with such a structure.

- Respective of lack of feedback in case of deviations in time and cost and quality of projects in governmental management systems of Iran, it is recommended that oil projects be left to the private sector.

The oil and gas industry and its projects are tightly related to the country's economy and one of the public budget income resources in developing countries. Oil and gas projects are also assumed as mega projects in the infrastructure of any oil country. Identification and prioritizing of delay factors in construction projects help the management and project team to plan for the right responses to these risks. Therefore, the findings of this research will provide a beneficial approach for oil construction management to deliver projects on time and improve construction project productivity. Oil construction project managers would understand any possible delays and risks during the construction phase better and formulate delay mitigation strategies properly (Kassem *et al.*, 2019).

Nevertheless, this study is not without its limitations. The consistency of the findings reported here can be improved by increasing the number of experts. It is also suggested to gather and investigate the opinion of different stakeholders, including owners, contractors and consultants.

Note

1. The technique for order of preference by similarity to ideal solution.

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