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Analysis of the performance of TAM in oil and gas industry: Factors and solutions for improvement

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ABSTRACT

Although it is well recognized that turnaround maintenance (TAM) projects are key determinant of the performance of oil and gas (O&G) companies, little is known about the factors that determine their performance and what solutions can be proposed to improve their reliability and efficiency. This paper aims at filling this gap. For this purpose, a focus group analysis was conducted to identify the factors affecting the performance of TAM projects and propose alternatives for improvement. Next, a questionnaire was administered with managers and practitioners of O&G TAM in Qatar to collect the required data set for the analysis. Using the Analytic Hierarchy Process (AHP) approach, our empirical findings reveal that the top five factors affecting TAM's performance in the O&G sector are labor skills, lack of supervision, communication skills, safety-related issues and on-site labor transportation. The study found that improving estimates of activities' durations and resources is the best solution to improve the performance of TAM in O&G companies.

1. Introduction

In the energy and engineering literature, it is well recognized that turnaround maintenance (TAM) activities are important components of the performance of manufacturing, process industries, and O&G companies (Faghihinial and Mollaverdi, 2012; Hey, 2019; Al-Turki et al., 2019). TAM activities are known to involve a comprehensive plant maintenance to optimize the useful life and efficiency of the company's equipment, reduce breakdowns and downtime, minimize energy use, reduce costs, and maximize production (Obiajunwa, 2012; Al-Turki et al., 2019). In the O&G industry, TAM is a crucial activity since it is associated with the highest cost incurred by O&G refineries (Ben-Daya et al., 2009; Obiajunwa, 2012) and requires high labor hours, long shutdowns and compliance with high safety and environmental standards (Al-Turki et al., 2019; Mohamed et al., 2017; Obiajunwa, 2012). TAM is carried out in O&G refineries usually every 4 years and lasts 1.5 months on average, requiring ∼300,000 labor hours.

TAM projects usually fail to fully achieve their objectives and targets. According to Obiajunwa (2012), only ∼80% successfully meet their target objectives, while Vichich (2008) argues that, on average, 83% of TAM projects fail to meet the full performance expectations, and in almost all TAM projects, the predicted targets for cost and time are exceeded by ∼20% on average. However, it is well acknowledged that TAM project failure can significantly reduce refinery's capacity and make it, at least in the short-term, hard to resume full productivity and efficiency (Pokharel and Jiao, 2008). In addition, O&G industry experts believe that failure to achieve TAM expectations increases the probability of major accidents. Indeed, incidents such as (i) the Suncor Altares drilling rig mechanical failure in March 2012 in Canada (British Colombia Oil and Gas Commission, 2013), (ii) the pipe rupture in the crude unit of the Chevron Refinery in Richmond, California, in August 2012 (CSB, Chemical Safety and Hazard Investigation Board, 2015a), (iii) the explosion of the Gulf of Mexico Deepwater Horizon Rig in April 2010 that killed 11 people and seriously injured 17 others (Chemical Safety and Hazard Investigation Board, 2016), and (iv) the Caribbean Petroleum Refinery explosion in October 2009 in Puerto Rico (Chemical Safety and Hazard Investigation Board, 2015b) are all directly or indirectly related to TAM.

It is also believed that lack of coordination, delays, or failures in major TAM of O&G plants can have an important effect not only on the companies concerned, but also on oil-dependent economies, international competition, and the energy market. For instance, the only time Qatar, a market leader in liquefied natural gas (LNG) exports, has ever been surpassed by another country was in November 2018 when maintenance activities caused a drop in Qatari LNG exports (Reuters, 2018). The challenge of international competition to maintain or increase market share created a need for oil-dependent economies to increase

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the reliability of their O&G industry and reduce TAM costs and duration.

We can assert from the discussion above that: (i) TAM is crucial for improving plant availability, safety and performance, (ii) its successful implementation has a significant impact on the performance of O&G companies, oil-dependent countries and the world energy market, and (iii) it requires effective and efficient planning, scheduling, coordination and execution. Surprisingly, despite the importance of TAM for O&G companies, oil-dependent economies and the global energy market, no significant research, to the authors' knowledge, has investigated the factors affecting its performance and the ways to improve future cycles. A review of TAM related literature shows that most studies have limited the analysis to the effect of only one type of factors on the performance (Hadidi and Khater, 2015; Javaid et al., 2016; Ghazali and Shamim, 2015; Lenahan, 2011; Duffuaa and Hadidi, 2017; Hess, 2009; Fiitipaldo, 2000; Ghazali et al., 2011; Oliver, 2002; Cruz et al., 2008; Megow et al., 2011; among others). This study aims to close this gap by exploring and ranking all important performance factors. In addition, while each existing work addresses a specific solution to improve TAM of O&G companies (Elwerfalli et al., 2016, 2019; Elfeituri and Elemnifi, 2007; Dyke, 2004; Bevilacqua et al., 2009), this paper proposes, assesses and ranks several improvement alternatives in order to select the best solution.

This paper offers several important contributions to O&G TAM. First, it proposes a general and methodological framework on how to select the key factors affecting the performance of TAM in O&G industry. In particular, it makes use of a focus group of professionals, experts and practitioners directly involved in O&G TAM projects followed by a questionnaire whose results were processed using the AHP technique (rarely used in this context despite its ease of replicability). Second, our study considers the case of Qatar, which is the largest exporter of liquefied natural gas in the world in 2018 (BP Statistical Review of World Energy, 2019) and one of the important exporters of oil[1]; the importance of Qatar in the global energy market makes the results beneficial to many O&G companies worldwide. Third, to the best of our knowledge, this paper is a unique study as it identifies and ranks the factors relevant to performance of TAM projects in the O&G sector and alternative solutions intended to improve the future cycles.

The remainder of this paper is structured as follows: Section 2 provides a brief review of the literature related to the factors affecting the performance of TAM in O&G and the proposed solutions for improvement, Section 3 explains the methodology, Section 4 presents the results, Section 5 discusses their implications, and Section 6 concludes the paper.

2. Related literature

A review of the energy and engineering literature highlights the existence of a large number of factors that can influence the performance of TAM projects and O&G companies. These factors can be categorized in several groups. While human factors, management factors, and technical factors are the most common groups, many others can be found in the literature.

Many studies are concerned with the factors affecting O&G companies. Holman et al. (2008) examined US labor productivity trends by sector and industry, including O&G, during 2000–2005, arguing that productivity changes reflect the current economic conditions, events and shocks, and long-term structural shifts. Rui et al. (2018), who examined the performance of the O&G projects in Nigeria (compared with its peers), highlight that while technical factors are not drivers of the performance, non-technical factors, including human and management factors, drive the poor performance. Noruzy et al. (2011) found that individual factors (e.g., job satisfaction and capability), organizational factors (participation, education, motivation and organizational communication) and occupational factors (role clarity, challenging work and autonomy) were important for improving the productivity and the performance of the Iranian oil industry. They also found that the factors affecting the performance of O&G projects are related to costs, scheduling, safety, technical indicators, quality, project size and field characteristics. Besides, the US Department uses ten groups (National Research Council of the National Academies, 2015).[2]

Some other works focused on the factors affecting TAM in O&G. The importance of human and management factors, as key for TAM performance, has been highlighted in many studies (Duffuaa and Hadidi, 2017; Hess, 2009). Fiitipaldo (2000) highlighted that workers' experience is important for ensuring basic quality throughout the process. Al-Turki et al. (2019) argued that miscommunication and shortage of (or misplaced) spare parts significantly affect TAM operations. Lenahan (2011) pinpointed the need for a committee involving all departments impacted by TAM activity because of its complexity and the many stakeholders associated with it. Several studies considered TAM planning to be the key factor (Ghazali and Habib, 2011; Oliver, 2002), whereas other studies emphasized the role of budget control (Motylenski, 2003; Roup, 2004). Cruz et al. (2008) and Megow et al. (2011) examined the importance of technologies and advanced management tools while Hameed and Khan (2014) estimated the risk-based TAM shutdown interval for TAM by considering the probability and consequences of failures.

Other factors highlighted in the literature on TAM of the O&G sector include safety (Dickey, 2002; Hadidi and Khater, 2015; Javaid et al., 2016; Schubert and Gannon, 2008); organizational aspects (Ghazali and Habib, 2011; Ghazali and Shamim, 2015); control, execution and evaluation (Duffuaa and Hadidi, 2017; Casa et al., 2009; Obiajunwa, 2012, 2013; Pokharel and Jiao, 2008; Utne et al., 2012););); sequential phases (Duffuaa and Ben-Daya, 2009; Lenahan, 2011); monitoring basic TAM parameters (Reiland and Busick, 2011); scope (Bertolini et al., 2009); measuring performance (Alsyouf, 2006; Bevilacqua et al., 2012; Duffuaa and Ben-Daya, 2004; Ghazali and Habib, 2011; Parida et al., 2015); learning and reporting (Cormier and Gillard, 2009; Houtermans et al., 2007; Lenahan, 2011) and planning (Murthy et al., 2002; Al-Turki, 2011). Overall, the importance of the factors seems to depend on the approach adopted and/or the country examined.

The literature related to the solutions proposed to improve the performance of TAM projects is relatively narrow and usually concerned with one specific alternative (Elwerfalli et al., 2016, 2019; Elfeituri and Elemnifi, 2007; Dyke, 2004; Bevilacqua et al., 2009). Elwerfalli et al. (2016) proposed decreasing TAM projects' duration and increasing the interval via a four-stage methodology for improving scheduling. Dickey (2002) highlighted an approach for improving plant TAM that prioritized safety and related practices to results; he reported improved schedule, cost-effectiveness and predictability, leading to improved overall economic performance. Bevilacqua et al. (2005) applied the business process re-engineering approach for improving TAM processes in oil refineries. Bevilacqua et al. (2009) used a constraint and risk-based assessment theory to explore the schedule and cost aspects

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[1] Oil and Gas exports in Qatar represent 85.2% of the total country exports in 2018, where natural gas exports represent 59.6% and crude oil 25.6%. Note that Qatar was a member of OPEC until January 2019.

[2] Schedule slip, phase schedule factors, schedule performance, schedule variance, preliminary and design engineering factors, phase cost factors, cost variance, cost growth, cost performance index, safety performance indices and safety performance measures.

of TAM processes in oil refineries. Other studies documented best practices to improve TAM (Militaru and Georgescu, 2009; Amendola et al., 2011; Hayes, 2002; Hayes and Clark, 2003; Pokharel and Jiao, 2008; Ghazali and Shamim, 2015; Karner and Toews, 2010).

3. Methodology

The framework we propose involves three phases, as summarized in Fig. 1: (i) the selection of the factors and alternatives, (ii) the collection of AHP input data through the administration of the questionnaire and (iii) the use of AHP to rank the factors and alternatives.

3.1. Phase one: Using a focus group to select the factors and alternatives

The literature review of the factors influencing the performance of TAM in O&G companies led to the pre-selection of 15 potential factors. A focus group of specialists, facilitated by one of the authors, met three times to examine the pre-selected factors, decide on their relevance to the performance of O&G TAM projects and classify them into groups. Eleven individuals participated in these meetings. The diversity of the participants, including TAM managers, coordinators and engineers, enriched the discussions and gave different perspectives on the selection. The meetings resulted in a final list of 17 factors arranged in four groups: technical factors, human factors, management factors and external factors (see Fig. 2 and Table 1).

The next step was to identify possible alternative solutions for improving the performance of O&G TAM. Each member in the focus group involved in the selection of the factors provided two alternatives, thereby yielding more than twenty proposed alternatives. The members worked together as a group to develop an affinity diagram where the similar alternatives were merged, which reduced their number to only seven. More extensive discussions within the group led to discarding four more alternatives that were judged less important, namely (i) the optimization of the contract strategy (which consists of a mix of lump-sum contracts and time-and-material contracts), (ii) the shifting from single contractor to multiple contractors, (iii) the coordination with other plants to have the TAMs at different times, and (iv) the optimization of the maintenance program to make it based on condition rather than time. The three alternatives that were kept are:

A1. Improving estimations of activities' durations and resources: the duration and cost of many activities are estimated from contractors' approximations, which are usually inflated. To reduce uncertainty, site surveys and benchmarking analyses should be conducted to determine more accurate estimations for the time required by each activity.

A2. Improving scheduling capabilities: The O&G industry is conservative in terms of TAM duration. The planning and scheduling team tries to start all activities as early as possible, which introduces a high workload in the first stages and leads to unbalanced use of resources and idle workers later on. The alternative is to prioritize activities according to criticality and resource requirements.

A3. Applying time-on-tool analysis: activities that do not add value usually constitute a large percentage of the work during TAM projects (e.g., transportation, control and preparation). The alternative involves conducting time-on-tool analysis, including site surveys to identify and target the major sources of waste.

3.2. Phase two: Using a questionnaire to generate the data required by AHP

The questionnaire had to be designed in such a way that would help collect the data needed for the application technique called AHP, a mathematical model for multi-criteria decision-making. AHP is actually a well-established approach whose applications extended to several areas, including management, engineering, agriculture, safety, and construction, to cite only few.[3] However, the application of this technique in the energy field in general and TAM projects in particular is still limited (Geng et al., 2018; Salvia et al., 2019; Kang et al., 2020; Galih and Narameth, 2019; Al-Tamimi and Al-Ghamdi, 2020). The AHP's main advantage is that it permits analysis with a small number of respondents (Hu et al., 2019). The key to applying AHP in our study was incorporating the experts' knowledge.

Let us assume n objects are to be evaluated according to a particular property. The objects in our case are either the factors or the alternative solutions, and the property is the contribution to TAM performance in O&G. The ultimate output of the AHP is the estimation of the relative weight w_i of each object $i = 1, 2, \ldots, n$ in terms of its contribution to the property; these weights satisfy the two properties $w_i > 0$ and $\sum_{i=1}^{n} w_i = 1$. AHP assumes that it is easier for the respondent to estimate the relative importance, $a_{ij} = \frac{w_i}{w_j}$, of factor i to factor j (the number of times factor i is more important than factor j) than to estimate the absolute weights w_i and w_j. The inputs of the AHP are, therefore, the pairwise comparisons of the objects that form the following $n \times n$matrix A that we refer to as the judgment matrix:

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

$$= \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

The number of comparisons needed for n factors is $\frac{n\times(n-1)}{2}$ (either the upper or the lower triangle of the matrix); this number would equal, in our case, 136 (since we have 17 factors). In addition, 51 comparisons would be needed to compare the respective impact of the three alternatives on each of the 17 factors. This would bring the total number of comparisons to 187 per respondent. To reduce the number of comparisons, we used the comparisons of the groups of factors (only 6 comparisons are needed for the 4 groups) in addition to those of the factors within each group (30 comparisons) and the comparisons of the respective impact of the three alternatives on each of the four groups (12 comparisons). This reduced the number of comparisons from 187 to 48.

Accordingly, a four-part questionnaire was designed where the first part focused on the collection of the demographics and the remaining three parts were designed to compare the importance of:

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[3] Currently, approximately 16,000 articles in ScienceDirect have mentioned this method. In addition, the seminal paper of Saaty (1988) introducing this method is cited more than 62,000 times.

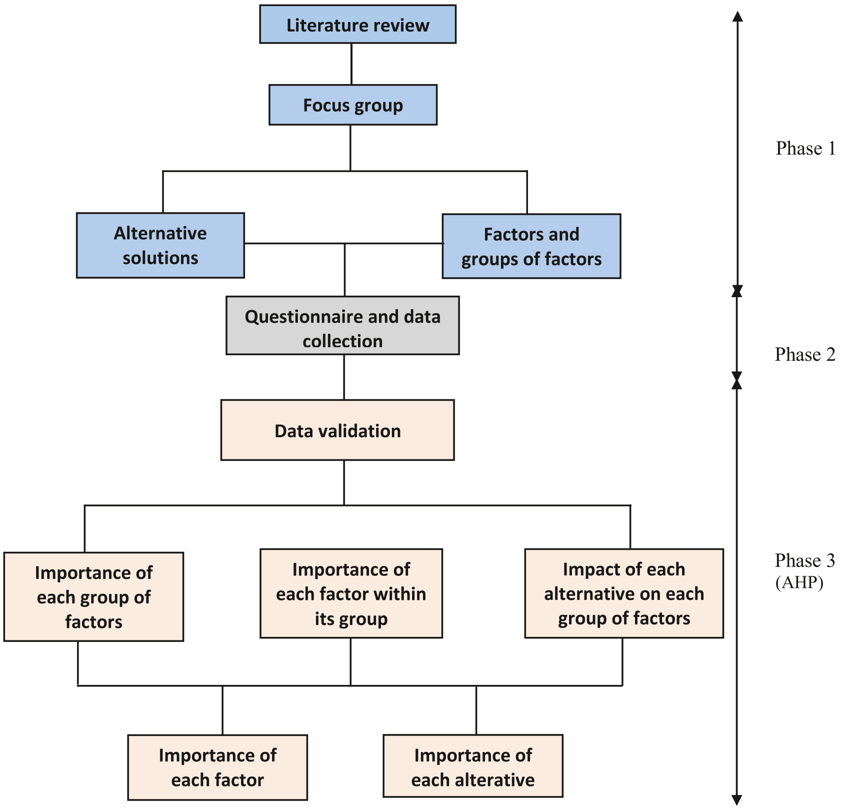


Fig. 1. Empirical methodology phases.

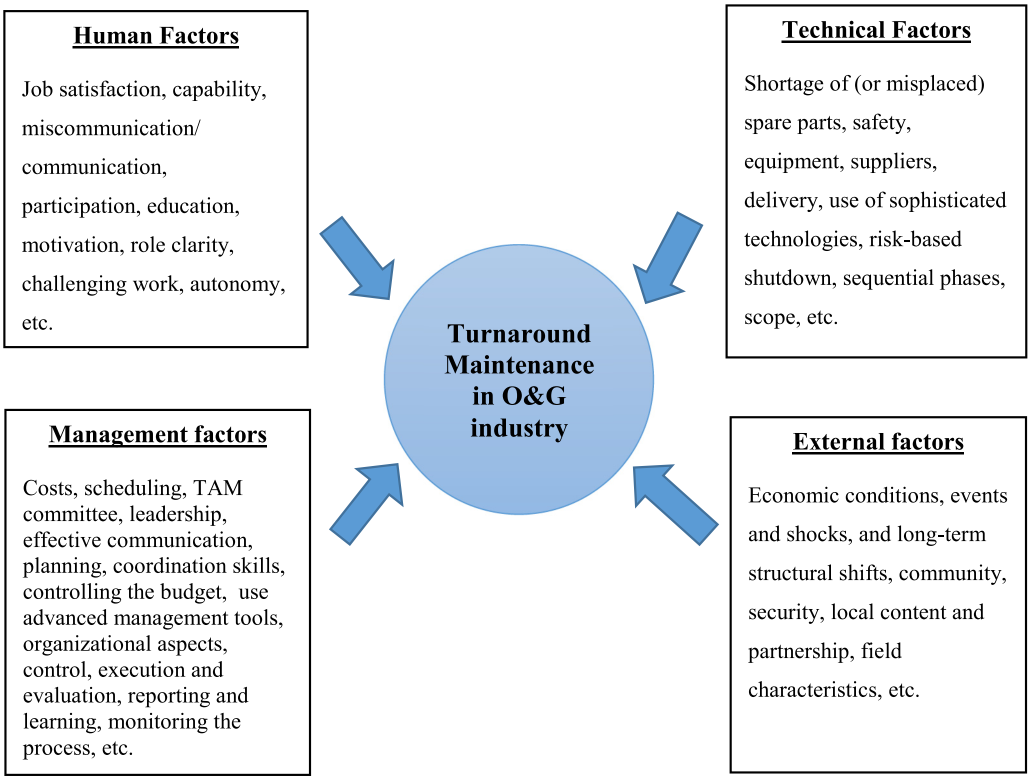


Fig. 2. The factors affecting the performance of TAM in O&G industry as found in the literature (clustered in four groups).

Table 1
Initial list versus final list of factors.

	Initial list		Final list	
		F1	Lack of tools and equipment	**G1. Technical Factors**
1	Clarity of project specifications	F2	Lack of instructions	
2	Rework	F3	Rework	
3	Stringent inspection by the engineer	F4	Inspection delays or stringency by the engineer	
4	Labor skills and experience	F5	Labor skills	**G2. Human factors**
5	Lack of financial incentive schemes, remuneration scale, physical fatigue	F6	Motivation and physical fatigue	
6	Poor communication, delays in responding to requests for information	F7	Communication skills	
7	Labor supervision	F8	Lack of supervision	
8	Lack of coordination; slow decision-making process	F9	Improper project coordination	**G3. Management factors**
		F10	Safety-related issues	
9	Extent of variation or change in orders during execution	F11	Poor project planning and scheduling	
10	Shortage of materials	F12	Unavailability of material on time at the workplace	
		F13	Crowded workplace	
11	Lack of transportation for the labor force	F14	Labor transportation on site	
12	Inclement weather	F15	Extreme weather	**G4. External factors**
13	Errors and omission in design drawings	F16	Recruitment and visa issues for timely recruitment	
14	Lack of managers' leadership	F17	Strikes	
15	Work subcontracted, working overtime			

- Each group of factors versus each other group.
- Each factor versus each other factor within the same group.
- The impact of each alternative versus each other alternative on each group of factors.

The respondents were provided with the needed information regarding the meaning of each factor, group of factors and alternative, as well as the pairwise comparison described above. Next, they were asked to make the three comparisons above bearing in mind that the responses are limited to the upper right-hand triangle of the judgment matrix. When comparing two factors (alternatives) i and j, one of two scales was used depending on whether i is more or less important than j. In the first case, the value of the respondent's judgment a_{ij} is estimated via a first nine-point scale, where the odd values 1, 3, 5, 7 and 9 denote "as important", "slightly more important", "fairly more important", "significantly more important", and "absolutely more important", respectively, while the even values 2, 4, 6 and 8 are used as intermediate values. In the second case, the respondent's judgment a_{ij} is estimated via an inversed scale where the odd values 1, $\frac{1}{3}$, $\frac{1}{5}$, $\frac{1}{7}$ and $\frac{1}{9}$ indicate "as important", "slightly less important", "fairly less important", "significantly less important", and "absolutely less important", respectively, while the even values $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{6}$ and $\frac{1}{8}$ are used as intermediate values.

The respondents were also requested to propose any other important factors that had not been included. The questionnaire took on average 90 min per respondent to complete. It would have taken more than four hours without the reduction of the number of comparisons.

3.3. *Phase three: Using AHP to rank the factors and the alternatives*

This phase consisted of using AHP technique to generate the rankings of the factors and the alternatives from the data produced by the questionnaire. It involved three steps. The first step embraced the validation of the data. The second step consisted of obtaining: (i) the weights of the groups of factors, (ii) the weights of the factors within each group (referred to as the factors' local weights), and (iii) the impacts of the alternatives on each group of factors (referred to as the alternatives' local weights). The third step used the weights obtained in the second step to produce the global weights of the factors and alternatives and rank them accordingly.

3.3.1. *Step one: Data validation*

The entries of the judgment matrix are supposed to satisfy the consistency condition stating that $a_{ij} = a_{ik}a_{kj}$, for $i, j, k = 1, 2, \ldots, n$ (Saaty, 1994). However, the respondents are providing judgments rather than exact values. In other words, they are providing $a'_{ij} \approx a'_{ik}a'_{kj}$ rather than $a_{ij} = a_{ik}a_{kj}$. The larger the difference between a'_{ij} and $a'_{ik}a'_{kj}$ the larger the inconsistency.

Let w be the vector of the weights of the n objects. If we multiply the judgment matrix A defined above by the weight vector w, we get:

$$Aw = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

$$= \begin{bmatrix} \frac{w_1}{w_1}w_1 + \frac{w_1}{w_2}w_2 + \cdots + \frac{w_1}{w_n}w_n \\ \frac{w_2}{w_1}w_1 + \frac{w_2}{w_2}w_2 + \cdots + \frac{w_2}{w_n}w_n \\ \vdots \\ \frac{w_n}{w_1}w_1 + \frac{w_n}{w_2}w_2 + \cdots + \frac{w_n}{w_n}w_n \end{bmatrix} = nw$$

As the actual entries of the judgment matrix are a'_{ij}, the problem becomes $A'w' = \lambda_{max}w'$, where λ_{max} is the largest or principal eigenvalue of the judgment matrix A'. To simplify the notation, we continue to use a_{ij} rather than a'_{ij}. Saaty (1994) showed that $\lambda_{max} \geq n$ and that A is consistent if and only if $\lambda_{max} = n$. The consistency index (CI), which is used to measure the relative extent by which λ_{max} exceeds n, is expressed by the formula $CI = \frac{\lambda_{max}-n}{n-1}$; the closer CI is to zero the higher the consistency. This index is compared to the average random index (RI), which is the average CI of a randomly generated judgment matrix where the conditions $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$ are forced. The ratio of the two indexes gives the consistency ratio (CR):

$$CR = \frac{CI}{RI} = \frac{\lambda_{max} - n}{(n-1)\,RI}$$

If $CR \leq 0.1$, the respondent is considered consistent in his/her judgment (the closer to zero the more consistent). Otherwise, the response should be reviewed by the respondent until the level is met. More details about CI, RI and CR can be found in Saaty (1994), Si et al. (2020) and D'Adamo et al. (2020).

3.3.2. Step two: Obtaining the weights of the groups of factors and the local weights of the factors and alternatives

The values of the weights can be obtained using the iterative method (Saaty, 1988). Let $A^{(k)} = \left[a_{ij}^{(k)}\right]$ be the k^{th} power of the matrix A; the larger the value of k the closer $\sum_{j=1}^{n} a_{ij}^{(k)} / \sum_{l,m=1}^{n} a_{lm}^{(k)}$ is to the value of w_i in the equation $Aw = \lambda_{max} w$. The power k is considered sufficiently large when $\sum_{j=1}^{n} a_{ij}^{(k)} / \sum_{l,m=1}^{n} a_{lm}^{(k)} \approx \sum_{j=1}^{n} a_{ij}^{(k+1)} / \sum_{l,m=1}^{n} a_{lm}^{(k+1)} \approx w_i$. We refer to the obtained vector of weights as the priority vector. In our case, nine priority vectors were obtained for each respondent r: One for the importance of the groups that we denote as w_G^r; four for the importance of the factors within each group that we denote as $w_{F|G1}^r$, $w_{F|G2}^r$, $w_{F|G3}^r$, and $w_{F|G4}^r$; and four for the impact of the alternatives on each group of factors that we denote as $w_{A|G1}^r$, $w_{A|G2}^r$, $w_{A|G3}^r$, and $w_{A|G4}^r$:

$$w_G^r = \begin{bmatrix} w_{G1}^r \\ w_{G2}^r \\ w_{G3}^r \\ w_{G4}^r \end{bmatrix};$$

$$w_{F|G1}^r = \begin{bmatrix} w_{F1|G1}^r \\ w_{F2|G1}^r \\ w_{F3|G1}^r \\ w_{F4|G1}^r \end{bmatrix}; w_{F|G2}^r = \begin{bmatrix} w_{F5|G2}^r \\ w_{F6|G2}^r \\ w_{F7|G2}^r \\ w_{F8|G2}^r \end{bmatrix}; w_{F|G3}^r = \begin{bmatrix} w_{F9|G3}^r \\ w_{F10|G3}^r \\ w_{F11|G3}^r \\ w_{F12|G3}^r \\ w_{F13|G3}^r \\ w_{F14|G3}^r \end{bmatrix};$$

$$w_{F|G4}^r = \begin{bmatrix} w_{F15|G4}^r \\ w_{F16|G4}^r \\ w_{F17G4}^r \end{bmatrix};$$

$$w_{A|G1}^r = \begin{bmatrix} w_{A1|G1}^r \\ w_{A2|G1}^r \\ w_{A3|G1}^r \end{bmatrix}; w_{A|G2}^r = \begin{bmatrix} w_{A1|G2}^r \\ w_{A2|G2}^r \\ w_{A3|G2}^r \end{bmatrix}; w_{A|G3}^r = \begin{bmatrix} w_{A1|G3}^r \\ w_{A2|G3}^r \\ w_{A3|G3}^r \end{bmatrix};$$

$$w_{A|G4}^r = \begin{bmatrix} w_{A1|G4}^r \\ w_{A2|G4}^r \\ w_{A3|G4}^r \end{bmatrix}.$$

The entries of the last eight vectors are local weights because they are all related to a specific group of factors. The last four vectors $\left[w_{A|G1}^r \; w_{A|G2}^r \; w_{A|G3}^r \; w_{A|G4}^r\right]$ form a 3×4 matrix referred to as the alternatives' impact matrix (AIM).

3.3.3. Step three: Obtaining the global weights of the factors and alternatives

The last step is to obtain the global weights of the factors (the importance of each factor as compared to the other factors, independently of the group to which it belongs) as well as the global weights of the alternatives (the importance of the impact of each alternative on all the groups of factors).

To determine the global weights of the factors, the weight of the group is distributed among the factors that constitute that group, proportionally to the weight of each factor in that group. Mathematically, this is equivalent to multiplying the priority vector of the factors within a group by the weight of the group as compared to the other groups. Let w_F^r be the priority vector for the 17 factors; the elements of w_F are:

$$w_{Fi}^r = w_{G1}^r w_{Fi|G1}^r \text{ for } i = 1, \ldots, 4$$

$$w_{Fi}^r = w_{G2}^r w_{Fi|G2}^r \text{ for } i = 5, \ldots, 8$$

$$w_{Fi}^r = w_{G3}^r w_{Fi|G3}^r \text{ for } i = 9, \ldots, 14$$

$$w_{Fi}^r = w_{G4}^r w_{Fi|G4}^r \text{ for } i = 15, \ldots, 17$$

On the other hand, the global weights of the alternatives depend on both the importance of the impact of the alternative on the group of factors and the importance of that group. Let w_A^r be the priority vector for the three alternatives; the elements w_{Ai}^r of w_A^r are obtained by multiplying the row i in the AIM by the groups of factors' priority vector w_G^r:

$$w_A^r = \begin{bmatrix} w_{A1|G1}^r & w_{A1|G2}^r & w_{A1|G3}^r & w_{A1|G4}^r \\ w_{A2|G1}^r & w_{A2|G2}^r & w_{A2|G3}^r & w_{A2|G4}^r \\ w_{A3|G1}^r & w_{A3|G2}^r & w_{A3|G3}^r & w_{A3|G4}^r \end{bmatrix} \times \begin{bmatrix} w_{G1}^r \\ w_{G2}^r \\ w_{G3}^r \\ w_{G4}^r \end{bmatrix}$$

$$= \left[w_{Ai}^r\right] = \left[\sum_{j=1}^{4} w_{Gj}^r w_{Ai|Gj}^r\right]$$

Denoting by n_R the total number of respondents, the importance of each factor, based on all respondents, is obtained as:

$$w_{Fi} = \frac{\sum_{r=1}^{n_R} w_{Fi}^r}{n_R}, \text{ for } i = 1, \ldots, 17$$

And the importance of each alternative, based on all respondents, is obtained as:

$$w_{Ai} = \frac{\sum_{r=1}^{n_R} w_{Ai}^r}{n_R}, \text{ for } i = 1, \ldots, 3$$

for

4. Results

In this section, we first describe how the data were collected and validated, and then we present the results obtained after processing the validated data by applying the AHP methodology described in the previous section.

4.1. Data description and validation

The original sample size consisted of 40 volunteers of experts and professionals. However, we stopped after obtaining 22 responses because starting from the fifth respondent, the rankings of the factors, groups of factors and alternatives became stable (i.e., the top five and lowest five were the same), thus diminishing the benefit of additional questionnaires (Figs. 3 and 4).

Fig. 5 shows that 45% of the respondents worked in upper management, 77% had >15 years of experience and ∼46% had > 20 years of experience.

The CR was used to validate the reliability of the data, where the acceptable range was < 0.1. The CR was calculated for each AHP matrix for the 22 respondents (see Section 3.3.1). In our sample, the CR values for each AHP matrix indicated that none

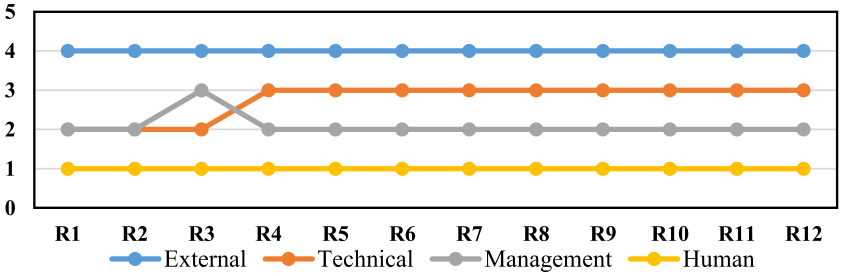


Fig. 3. Ranking trend of the factor groups in TAM.

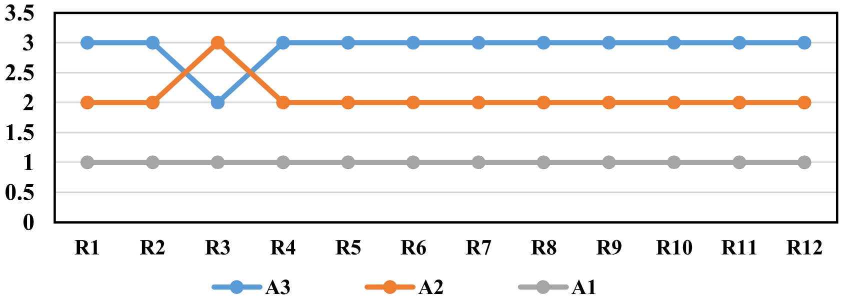
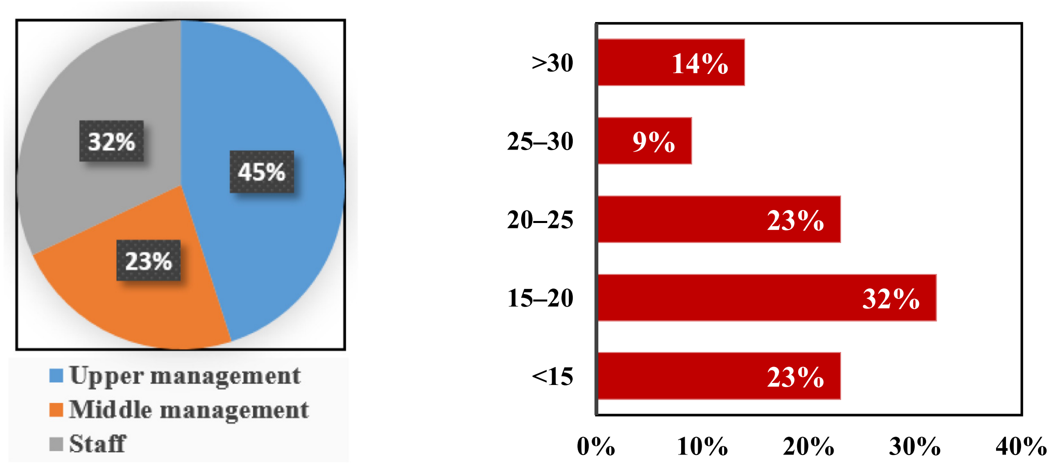


Fig. 4. Ranking trend of the alternatives in TAM.



(a) % of respondents per occupation (b) % of respondents per intervals of years of experience

Fig. 5. Respondents description based on role and years of experiences.

of the responses was outside the range (the maximum value was 0.099, which was found for the management factors group). This result provides strong evidence for the respondents' consistency and validates the data.

Moreover, to assess the data's variability, we used Chebyshev's theorem, which states that at least 75% of the data must be within two standard deviations to be acceptable (Salman et al., 2007). For our data, over 92% of the observations were within this range, which was considered yet another validation of the data.

4.2. Ranking the groups of factors

The application of AHP resulted in 198 AHP matrices (each of the 22 respondents had to complete the nine matrices explained in Section 3.3.2). For illustration, we present in Table 2 the results of the pairwise comparisons and calculate weights for the first matrix of one respondent only.[4] The upper part of the table shows the relative importance of the groups of factors for one randomly selected respondent while the lower part shows the normalized matrix, the priority weights and the consistency data for the same respondent.

For this respondent, human factors (G2) and management factors (G3) were the most important, followed by the technical factors (G1) then the external factors (G4). The upper part of the table shows that human factors and management factors were three times as important as technical factors and nine times as important as external factors, whereas technical factors were three times as important as external factors. This is confirmed by the priority vector w_G^r in the lower part of the table, where the weights of human factors and management factors are the largest (0.4025 for both). The CR was 0.012, which is below the 0.1 threshold. Identifying each factor's relative importance

Our analysis of the individual factors' relative importance was similar to that of the groups. Local weights for the factors within

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[4] The results of all individual respondents are available upon request.

Table 2
Estimation of the importance of the groups of factors for one respondent.

Pairwise comparison						
	G1	G2	G3	G4		
G1	1	1/3	1/3	5		
G2	3	1	1	9		
G3	3	1	1	9		
G4	1/5	1/9	1/9	1		
Sum	7.20	2.44	2.44	24.00		
Synthesized or normalized column matrix						Consistency data
	G1	G2	G3	G4	Priority vector	
G1	0.139	0.136	0.136	0.208	0.1550	$\lambda_{\max}$ (Eigenvalue) = 4.04
G2	0.417	0.409	0.409	0.375	0.4025	*CI* (Consistency Index) = 0.011
G3	0.417	0.409	0.409	0.375	0.4025	*RC* (Random Consistency) = 0.9
G4	0.028	0.045	0.045	0.042	0.0401	*CR* (Consistency Ratio) = 0.012

each of the groups were drawn from the judgment matrix. Table 3 provides the estimation by the selected respondent of the importance of the factors within the group of human factors.

For each respondent, the global weights for each of the 17 factors were calculated by multiplying the local weight by the weight of the corresponding group of factors. Back to the selected respondent, the local weight of labor skills ($w^r_{F5|G2} = 0.5579$ as shown in Table 3), multiplied by the weight of the human factors group ($w^r_{G2} = 0.4025$ as shown in Table 2) results in a global weight of $w^r_{F5} = 0.2245$.

After developing the global weights for all 17 factors for each respondent, the average weights are calculated and the factors are ranked as shown in Fig. 6. The top five factors (in green in the figure) are: (i) labor skills, (ii) the lack of supervision, (iii) communication skills, (iv) safety issues and (v) on-site labor transportation. Note that these factors belong to human and management factor groups and, together, contribute by 54.83% to TAM performance.

When reviewing the literature for results comparison motives, we found only one study quantifying and ranking the factors affecting TAM performance; it is the work of Duffuaa and Hadidi (2017), which is related to the performance of TAM in a large-scale petrochemical complex of several plants in Saudi Arabia. The authors used the modified quality function deployment methodology to investigate the impact of 32 factors (named technical requirements in their case) clustered in 10 groups (named attributes in their case). Although their results are in line with ours regarding the importance of the top factors, the numerical comparison is not sensible mainly because they calculate the weight for each factor within its group without providing the weights of the groups, which makes it impossible to find the absolute weight of the factors.

4.3. Identifying the relative importance of the improvement alternatives

The third level of our analysis involved calculating the weights of the proposed alternatives for improving the TAM performance. The three alternatives are: (i) improving the estimation of activities' durations and resources, (ii) improving scheduling capabilities and (iii) applying time-on-tool analysis. The AIM for the selected respondent is:

$$\left[w^r_{A|G1} w^r_{A|G2} w^r_{A|G3} w^r_{A|G4}\right] = \begin{bmatrix} 0.6923 & 0.6687 & 0.1062 & 0.2431 \\ 0.0769 & 0.2431 & 0.6333 & 0.6687 \\ 0.2308 & 0.0882 & 0.2605 & 0.0882 \end{bmatrix}$$

Each row i in the AIM displays the impact of alternative i on each of the four groups of factors. For example, according to the selected respondent, A1 has more impact on G1 ($w^r_{A1|G1} = 0.6923$) and G2 ($w^r_{A1|G2} = 0.6687$) than on G3 ($w^r_{A1|G3} = 0.1062$) and G4 ($w^r_{A1|G4} = 0.2431$).

The weights of the alternatives are obtained as explained in Section 3.3.3. For example, the weight of A1 for the selected respondent equals the product of the AIM above and the priority vector for the groups of factors (provided in Table 2):

$$w^r_{A1} = \begin{bmatrix} 0.6923 & 0.6687 & 0.1062 & 0.2431 \end{bmatrix} \times \begin{bmatrix} 0.1550 \\ 0.4025 \\ 0.4025 \\ 0.0401 \end{bmatrix}$$
$$= 0.429.$$

That is, the relative impact of the selected alternative solution on TAM performance is 42.9%. The weights of the other alternatives for the same respondent are calculated in a similar way and are 39.1% and 18.0%, respectively.

After developing the weights of the alternatives for each respondent, the average for all respondents was calculated, as shown in Table 4. These average weights indicate that A1 was the most important alternative.

5. Discussion

In this section, we discuss the results presented in the previous section focusing first on the top factors and second on the best alternative.

5.1. Top five factors affecting TAM performance

The results obtained from this study reveal that the top five factors influencing the performance of TAM projects in the Qatari O&G companies are: (i) labor skills, (ii) lack of supervision, (iii) communication skills, (iv) safety issues, and (v) onsite labor transportation. The following discussion reflects on these factors and compares them with the main findings in the literature.[5]

The ranking of "labor skills" as the top factor influencing the performance of TAM projects can be mainly explained by the fact that workers in TAM projects lack the needed skills (Obiajunwa, 2013; Al-Turki et al., 2019). Moreover, TAM professionals and experts involved in the focus group argue that these workers might be assigned tasks they have never executed before or trained for, and are rotated frequently before gaining experience in a specific task. Therefore, the workers are often not used efficiently. This is in line with the finding of Fiitipaldo (2000) who highlighted the importance of workers' experience in ensuring basic quality

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[5] At this level it is worth mentioning that material shortages and the lack of tools were highlighted among the most important factors in much of the literature (Cruz et al., 2008; Megow et al., 2011) but they ranked in the lowest five factors in our case (12th and 14th, respectively). This can be explained by the strong financial position of Qatari companies, which allows them to pay a premium to obtain materials faster and have tools and equipment ready on time. In addition, Qatar does not have strong labor unions, which explains why strikes ranked lowest.

Table 3
Estimation by one respondent of the importance of the factors within the group of human factors.

Pairwise comparison

	F5	F6	F7	F8
F5	1	7	5	3
F6	1/7	1	1/3	1/5
F7	1/5	3	1	1/3
F8	1/3	5	3	1
Sum	1.68	16.00	9.33	4.53

Synthesized or normalized column matrix weights						Consistency data
	F5	F6	F7	F8	Priority vector	
F5	0.597	0.438	0.536	0.662	0.5579	λ_{max} (Eigenvalue) = 4.177
F6	0.085	0.063	0.036	0.044	0.0569	*CI* (Consistency Index) = 0.039
F7	0.119	0.188	0.107	0.074	0.1219	*RC* (Random Consistency) = 0.9
F8	0.199	0.313	0.321	0.221	0.2633	*CR* (Consistency Ratio) = 0.025

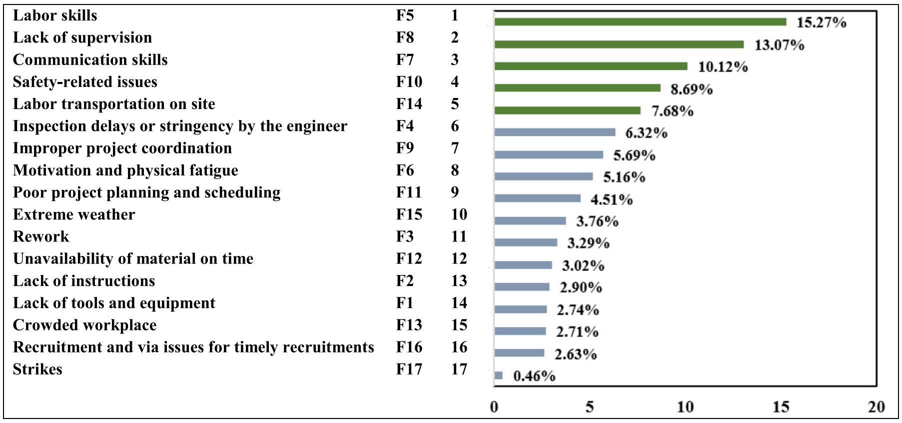

Fig. 6. Ranking and average weights of the factors.

Table 4
Average weights and ranking of the alternatives for all respondents.

Alternatives	Weights	Rank
A1: Improving the estimation of activity time and resources	0.4353	1
A2: Improving scheduling capabilities	0.3341	2
A3: Applying Time-On-Tool analysis	0.2304	3

during all TAM phases. It is worth noting that, according to the focus group experts, despite the awareness of the need for the development of TAM workforce, the high costs associated with training a massive number of workers, the short duration of projects and the unlikelihood that the same workers will be used in future projects discourage contractors from offering practical solutions to this problem.

Regarding the "lack of supervision", it is important to distinguish between two types of supervision: contractor's labor supervision and area supervision. While the first one is part of the duties of the contractor, the second one is the company's responsibility. In the same area, there are usually many teams working simultaneously. A typical area supervisor is expected to ensure the availability of the needed resources (tools and material), timely transportation of workers, commitment to safety procedures, coordination between the different teams to avoid duplications and manage crowds, etc. The "lack of supervision" in this context arises because O&G companies are not able to provide the needed number of area supervisors. This is mainly due to the occasional aspect of the TAM projects, which constrains the O&G companies from having a sufficient number of area supervisors.

As for "communication skills", given that TAM involves thousands of employees, divided into small inter-dependent teams, communication becomes a real challenge. According to Al-Turki et al. (2019), miscommunication between different units is the main cause of delays in schedule time, shortage of (or misplaced) spare parts, and budget overdue, thus incurring significant financial losses. The large number of workforce and the diversity in language, culture, and social issues are among the reasons behind the lack of communication between workers and their superiors. Our results are in line with Duffuaa and Hadidi (2017) who found communication to be a significant factor for the performance of TAM in O&G companies. Bringing back the workers who had already been part of the workforce in previous projects would reduce communication issues thanks to their acquired familiarity with locations, procedures and job requirements.

"Safety issues" might be a disturbing factor or a constraint for the advancement of work if not well managed. For instance, an emergency or alarm (false or correct) may lead to the evacuation of thousands of workers (and probably dozens of tools and equipment) from the field (which involves transportation, counting people, etc.) and interruption of work possibly for several hours. The return of the employees to their work locations (after the threat or danger is resolved) would usually require the issuance of new permits, verification of many protocols and implementation of all safety procedures. Hence, handling safety related issues and ensuring proper application of all procedures to avoid alarms and emergencies will have a positive impact on the TAM performance. Dowd and Daher (2012) argue that safety management has a crucial role in the turnaround activity and they propose indicators for TAM safety issues. Many other studies consider safety to be an important factor in O&G TAM (Bevilacqua et al., 2009; Dickey, 2002; Hadidi and Khater, 2015; Javaid et al., 2016; Schubert and Gannon, 2008).

Concerning "on site labor transportation", there are four challenges associated with this issue, according to our focus group experts. First, the production sites are located in remote areas, which calls for traveling long distances. Second, TAM requires a massive labor force, thus necessitating a large number of vehicles. Third, safety procedures and protocols need to be followed when workers are transported from one location to another, which may lead to delays. Fourth, O&G companies are very strict about access to their plant or site, which makes the flow of labor on and off the site subject to many restrictions.

5.2. Best alternative solution for improving TAM performance

Among the three investigated alternatives, our results suggest that "improving estimations of activities' durations and resources" (A1) is the best alternative solution for improving the performance of TAM in Qatari O&G companies. We describe below the impact of this alternative on the top five factors discussed above, as explained by the members of the focus group.

To understand to what extend this alternative impacts "labor skills", it is important to note that contractors' estimations of needed resources are usually inflated, especially manpower. Given the scarcity of skilled workers, contractors usually resort to less skilled workers. An accurate estimation of activity time and resources (i.e., A1) would reduce the proportion of unskilled labor. Similarly, over estimation of activity time and resources would result in more workers, crowded areas, and more challenging tasks (transportation, coordination, etc.) for area supervisors, thereby accentuating the "lack of supervision".

Conversely, good estimation of activities' durations and resources would make it more likely to bring back the workers with job experience in previous TAM projects. This would reduce "communication issues" involving familiarity with locations, procedures and job requirements as well as help bolster on-site interaction. Similarly, with a reduced number of workers, safety procedures, protocols and emergencies (alert, evacuation, count, work suspension, resuming work, etc.) can be handled more efficiently, which would help improve the management of "safety issues". Also, the reduction of the number of workers would result in better scheduling of "on-site labor transportation".

It is worth noting that alternative A2, improving scheduling capabilities, though not ranked first, has a significant impact on improving TAM performance. For instance, improving scheduling capabilities would help prioritize activities according to criticality and resource requirements. This would help avoid front loading in schedule and balance the use of resources. This alternative has a positive effect on the selection of skilled labor, supervision and labor transportation, but no clear impact on communication and safety factors. On the other hand, 'applying time-on-tool analysis' is helpful in identifying the waste by observing and recording tasks from start to finish, in addition to identifying areas where labor is more sluggish and trying to solve it. However, this alternative is costly and has no clear impact on any of the concerned factors.

6. Conclusions

This study aimed to provide new insights into the factors affecting the performance of TAM projects in the O&G sector in Qatar and propose solutions for improvement. The analysis was conducted in three main phases. The objective of the first phase was to select the factors that can potentially affect TAM performance and the alternatives that may be adopted to improve it. To this end, a focus group led by one of the authors was formed from managers, TAM experts, engineers and professionals who had influence on the decision-making process in O&G TAM projects. The objective of the second phase was to produce reliable data in order to ensure the proper application of the AHP technique. One of the authors, the leader of the focus group, conducted all interviews. Finally, in the third phase, the AHP technique was used to validate the data and rank the factors and alternatives. Our results show that the top five factors that significantly affect the performance of TAM projects on O&G are: (i) labor skills, (ii) the lack of supervision, (iii) communication skills, (iv) safety issues and (v) on-site labor transportation. Concerning the ranking of the alternatives, our analysis shows that 'improving the estimation of activities' durations and resources' is the best way to improve the performance of O&G TAM in Qatar.

Although our analysis was conducted using a sample of O&G companies in Qatar, we believe that it can be generalized to other countries with similar economic outlook and culture. Therefore, we would expect that the factors affecting the performance of O&G TAM in these countries and their relative importance to be similar to those in our study. However, conducting this study in different countries would allow us to confirm the results.

To the authors' knowledge, this is the first study that calculates the relative weights and ranks of all factors affecting TAM performance in O&G companies as well as the weights and ranks of the improvement actions. Though our work is related to TAM of O&G companies in Qatar, it can be applied to many megaprojects and facilities in other industries and can trigger new research prospects for other scholars towards calculating the absolute weights of all factors in these projects and ranking them.

Finally, like any research, this work has some limitations that can be improved in future research. First, as the respondents' personal perceptions may differ depending on their status (i.e. workers, engineers, technicians, contractors and other professionals), we believe that involving more people related to O&G TAM projects would result in better cognizance of the factors affecting the performance of these projects. Second, the open-ended question in the questionnaire revealed other factors that could be further researched, such as contractors' restrictions, lack of quality inspection and external conditions. In particular, the restrictions on the selection of contractors may turn out to be a major factor negatively affecting O&G TAM projects. Indeed, a high load is being placed on the limited number of qualified local contractors, who are often handling multiple projects simultaneously. The problem is even worsened by the absence of coordination among companies in the O&G industry to schedule their TAM projects at different times.

This study may be extended to investigate the relationship between TAM project, and economic resilience and sustainability (Elmqvist et al., 2019; D'Adamo and Rosa, 2020). The analysis of the impact of policies and measures designed to reduce greenhouse gases emissions on the TAM performance is also an important area for future research.

CRediT authorship contribution statement

Abdulhadi Nasser Al-Marri: Term, Software, Investigation, Resources, Conceptualization, Methodology, Formal analysis, Project administration. **Salem Nechi:** Writing - original draft, Writing - review & editing, Validation, Formal analysis, Supervision, . **Omar Ben-Ayed:** Writing - original draft, Writing - review & editing, Validation, Methodology, Formal analysis, Supervision, Project administration. **Lanouar Charfeddine:** Writing - original draft, Writing - review & editing, Conceptualization, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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