AN ANALYSIS OF THE CRITICAL RISK FACTORS IN OIL AND GAS PIPELINE PROJECTS USING A COMPREHENSIVE RISK MANAGEMENT FRAMEWORK

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Risk Factors (RFs) associated with the design, construction and operation of Oil and Gas Pipeline (OGP) projects have a serious impact on the safety of a project. The limitations of the effective risk analysis techniques due to a lack of reliable risk data - particularly in insecure countries like Iraq where OGPs are suffering from sabotage attacks - frequently cause great challenges in the attempt to mitigate these risk factors and provide a systematic risk management system. This paper, therefore, aims to analyse OGPs' RFs more accurately using a more systematic and holistic Risk Management Framework (RMF). The RMF was designed under three steps. Step 1 focused on carrying out a comprehensive review to identify the RFs in OGP projects in different countries and some of the Risk Mitigation Methods (RMMs) used in these projects. Step 2 used a questionnaire survey to analyse the RFs regarding their influence on OGP projects and to evaluate the RMMs based on their degrees of effectiveness to mitigate the RFs. The ranking of the RFs indicated that proper attention needs to be paid to the question of what motivates third-party disruption to OGPs in Iraq like sabotage, terrorism and theft risks. Step 3 was about recommending some RMMs to mitigate the RFs in these projects based on the results of the survey. The RMF and its recommendations could be used to more effectively manage the RFs in OGP projects in troubled countries that have just begun to address such risks.

Keywords: pipelines, risk management framework, risk mitigation methods

INTRODUCTION

Although Oil and Gas Pipelines (OGPs) are a safe mode by which to transport petroleum products, these pipelines are still subject to several threats that cause pipe failure. OGPs mainly suffer from Third-Party Disruption (TPD); corrosion; planning, design and construction defects; natural hazards; and operational errors (Wan and Mita, 2010). Peng *et al*., (2016) define TPD as any accidental damage in OGPs due to external Risk Factors (RFs) like soil movement, surface loads that compress pipelines, natural phenomena, mechanical failures, or human activities near to pipelines. Muhlbauer (2004) suggested that TPD also refers to any direct or indirect action that may be carried out individually, or by groups, to affect the safety of OGP projects - like terrorism, sabotage, theft and cyber-attacks on control systems. TPD has been recognised as one of the most dominant causes of OGP failure globally (Wan and Mita, 2010).

Iraq's oil reserves are the fifth-largest in the world (EIA 2016) and its gas reserves range between the world's 10th to 13th largest (IEA 2012). Meanwhile, the inadequacies regarding the management of the RFs in OGP projects make pipeline failures inevitable

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and hinder oil export activities, which results in massive economic losses to the country. Hence, there is a vital need to contribute to solving these highlighted crucial problems in Iraq and other troubled countries by employing a holistic risk management method to focus on the most vulnerable segments of pipeline safety. This research, therefore, aims to develop a Risk Management Framework (RMF) to identify and analyse the RFs and Risk Mitigation Methods (RMMs) in OGP projects more systematically and holistically to help the stakeholders to mitigate the RFs in these projects successfully.

LITERATURE REVIEW

As Peng *et al*., (2016) observed, risk management has four steps: (1) Identify the RFs and RMMs. (2) Analyse the RFs regarding their degree of influence on a project because dealing with each RF as if it is the most critical one results in heavy losses in terms of resources (Srivastava and Gupta, 2010). (3) Respond to the risk and mitigate the consequences, which means to apply suitable methods to mitigate the RFs. Therefore, it is significant to evaluate the RMMs regarding their degree of effectiveness. (4) Risk monitoring and control, which is a continuing work-cycle of the three steps to provide up-to-date information about the existing and new RFs and RMMs during the project's stages, and to ensure the project's safety.

Effective risk mitigation requires appropriate knowledge, an up-to-date database about pipeline failure causes (Balfe *et al*., 2014), and accurate values about the probability and severity levels of the RFs to identify the factors which require prioritisation. However, the data that the existing risk analysis methods contain is uncertain with regard to the probability and severity of the RFs. For example, the data is it not available or is there a possibility that it is incorrect. (Yazdani-Chamzini, 2014). In addition, these methods are not accurate enough to calculate the probability of TPD risks because a historical database about such risk has not yet been established (Peng *et al*., 2016). Moreover, these methods are either too generic or too specific when dealing with the RFs, as they are analysing only one or two RFs at the same time (El-Abbasy *et al*., 2016). For example, studies about OGP risk in European countries mainly focus on corrosion and stress-strain risk. This is because OGPs in these countries are less subject to sabotage risk because their pipelines are underground and in safe areas. Researchers in the USA are focusing more on the terrorism risk, especially after 9/11, in addition to corrosion because OGPs in the USA are underground. Studies about this topic in Africa are focusing more on the social factors of risk, such as sabotage and thefts. This is related to poverty levels, as stolen products might be sold on the black market. Therefore, these studies are not applicable in Iraq or other countries in a similar situation where the OGP network is aboveground, and they are subject to all of the mentioned RFs.

Regarding the development of RMF, Mubin and Mubin (2008) developed a risk model for gas pipeline projects in Pakistan. This model identifies the RFs during the construction stage based on analysing a number of local projects and reviews from local clients and contractors. Monte Carlo simulation was used to estimate finishing the projects on time and budget. The authors created a data bank to store the model's findings and provide recommendations for the risk management process. Schwarz *et al*., (2015) proposed a risk management procedure to support decision-making processes in projects. The model started by defining the project's scope, the risk management criteria and identifying the RFs using checklists. The authors used the Artificial Neural Network (ANN) and experts' judgements to evaluate the RFs. These two models identify RFs only from local projects. El-Abbasy *et al*., (2014) used a historical database and ANN to predict the conditions of offshore OGPs in Qatar and to prioritise the maintenance work for these pipelines. This study uses an available database to identify the RFs. Unfortunately, there is no such database available in developing countries, where the documentation is not in the best condition and there are no appropriate records about OGP accidents. None of the reviewed models has identified and evaluated any RMMs to mitigate the RFs. The current study adapts these models to develop a more holistic and applicable RMF for OGP projects in troubled countries like Iraq by bridging the highlighted gaps in them (see Figure 1).

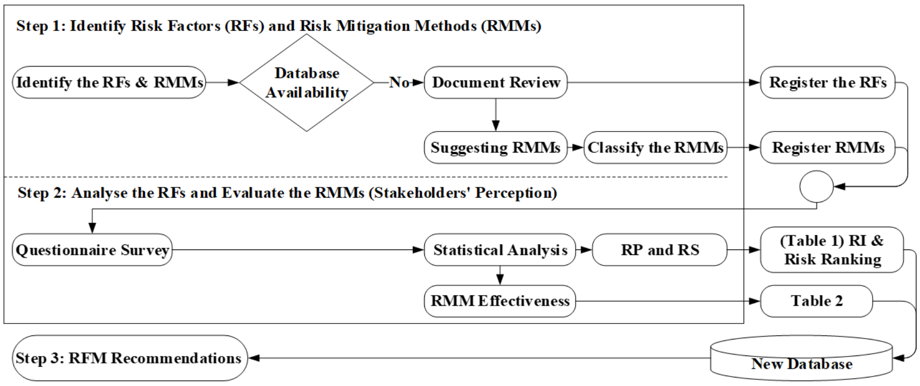

Figure 1: The design of the Risk Management Framework (RMF)

From the preceding text, it is clear that effective risk management is unachievable if the facilities for identifying the RFs and RMMs are not at the required level, and the probability and severity of the RFs and the effectiveness of the RMMs are not accurately evaluated.

Comprehensive investigations were carried out to identify OGP RFs in different countries across the world, especially in insecure ones. These investigations helped to overcome the problem of lack of information about OGP failure causes in Iraq, because there is no database about them. Li *et al*., (2016) classified factors influencing global investment in shale gas into five types, namely: economic, political, geological, technological and internal risks. Mubin and Mubin (2008) classified RFs that obstruct the construction and operation of pipeline projects in Pakistan into seven types, namely: political, socio-economical, technical, organisational, natural catastrophe, financial, safety and security, and environmental risks. In the current study, in order to include OGP RFs that affect the general safety of OGPs in addition to the economic challenges, and to include RFs present during the entire project, they have been classified into five different types depending on their characteristics, as follows: (I) Security and Societal (S&S); (II) Pipeline Location (PL); (III) Health, Safety and Environment (HSE); (IV) Operational Constraints (OC); and (V) Rules and Regulations (R&R) risks (see Table 1).

RESEARCH METHODOLOGY

Developing an RMF is a part of the methodology in this paper. Figure 1 explains the steps of work for this framework. Step 1 was about identifying the RFs from the literature review. Additionally, a number of RMMs were suggested to mitigate the RFs in OGP projects in Iraq. These methods were classified depending on an estimate about when they could be applied during the projects (see Table 2). These investigations did not provide any information about the probability and severity of the RFs and the effectiveness of the RMMs in the study area, Iraq. Therefore, a questionnaire survey was needed to gather stakeholders' perceptions about them.

Step 2, therefore, saw the development of a questionnaire survey based on the findings from step 1. A pilot survey was distributed to improve the clarity of the questions. The survey was distributed using an online survey tool. The potential respondents were informed that their responses would be treated confidentially. RF probability levels were analysed on a scale (rare, unlikely, possible, likely and almost certain). RF severity levels were analysed on a different scale (negligible, minor, moderate, major and catastrophic). RMM effectiveness degrees were evaluated on a further scale (ineffective, slightly effective, moderately effective, very effective and extremely effective). A Likert scale was used in this paper because it is a commonly used scale for subjective measurements. This scale is sensitive and small deviations are highly meaningful (Cummins and Gullone, 2000). Initially, a 7-point Likert scale was used in the pilot survey, but the participants observed that it was difficult for them to use. Therefore, a 5-point scale was suggested for the survey. The survey asked the participants to rank the project stages from 1 to 3 regarding their priority for application of the RMMs; where 1 means high priority and 3 means lower priority. The respondents were asked, are the underground pipelines (which are subject to corrosion, geological, construction and maintenance risks) safer than the aboveground ones (which are subject to sabotage and theft risks) or vice versa?

The values of Risk Probability (RP) and Risk Severity (RS) of each RF (Table 1) and the degrees of effectiveness of each RMM (Table 2) were calculated by determining the means of the scale. Based on the character of the RF, some RMMs were suggested to mitigate the RF. For example, avoiding insecure areas, using an anti-terrorism design, having protective barriers and patrols could mitigate the risk of terrorism and sabotage by direct action. Meanwhile, laying the pipelines underground can help to minimise the opportunities for terrorists and saboteurs to attack them. However, terrorists and vandals still have an opportunity to damage OGPs. Educating government-public corporations about managing the safety of OGPs and reporting any case of vandalism could help to reduce pipeline attacks, but the government cannot entirely stop terrorists and vandals from attacking the pipelines. From these examples, the RMMs were classified into direct and indirect RMMs in the way that the RMM(s) will mitigate the RF(s) (see Figure 2).

RESULTS

Before analysing the survey, it was important to test its reliability. Cronbach's alpha correlation coefficient (α) was calculated by using SPSS to test the survey's reliability level (Shavelson and Haertel, 2006). The α of the survey was found to be 0.910, where 0.7 indicates a minimum level of reliability (Pallant, 2001). This means the results are reliable.

In total, 198 respondents completed the survey: 14 were consultants, planners or designers; 71 were site engineers; 41 were operators; 29 were administrators; 10 were owners or clients; and 33 were either students (they are employers and postgraduate students at the same time) or lecturers in oil engineering departments at different Iraqi universities. With regard to level of experience, 74 respondents have less than five years of experience, 67 have between five and 10 years, 29 have between 10 and 15 years, and 28 have more than 15 years of experience. Three respondents do not have a degree, 28 have a high school certificate or diploma, 106 have a bachelor's degree (engineers), and 61 have a master's degree or PhD. The results of analysing the RFs and RMMs are shown in Table 1 and Table 2.

Table 1: The identified RFs from literature and the results of the survey.

RFs	Authors	Risk Type		RS	RI	R*
Terrorism and sabotage	Nnadi *et al*., (2014)	S&S	3.99	4.49	3.58^	1
Corruption	Nnadi *et al*., (2014)	R&R	3.98	4.32	3.44	2
Insecure areas	Srivastava and Gupta (2010)	PL	3.72	4.11	3.06	3
Lawlessness	Peng *et al*., (2016)	R&R	3.61	4.19	3.03	4
Thieves	Nnadi *et al*., (2014)	S&S	3.69	4.08	3.01	5
Corrosion and lack of protection against it	Nnadi *et al*., (2014)	OC	3.69	3.99	2.94	6
Improper safety regulations	Guo *et al*., (2016)	HSE	3.69	3.95	2.92	7
Improper inspection and maintenance	Nnadi *et al*., (2014)	HSE	3.66	3.92	2.87	8
Low public legal and moral awareness	Peng *et al*., (2016)	S&S	3.71	3.86	2.86	9
Weak ability to identify and monitor the risks	Nnadi *et al*., (2014)	OC	3.63	3.90	2.83	10
Stakeholders not paying proper attention	Nnadi *et al*., (2014)	R&R	3.53	3.96	2.80	11
Lack of proper training	Nnadi *et al*., (2014)	R&R	3.65	3.77	2.75	12
Exposed pipelines	Rowland (2010)	HSE	3.67	3.68	2.70	13
Shortage of modern IT services	Nnadi *et al*., (2014)	OC	3.67	3.65	2.68	14
Limited warning signs	Nnadi *et al*., (2014)	HSE	3.63	3.66	2.66	15
Easy access to pipeline	Srivastava and Gupta (2010)	PL	3.63	3.65	2.65	16
Lack of risk registration	Nnadi *et al*., (2014)	R&R	3.57	3.70	2.64	17
Little research on this topic	Nnadi *et al*., (2014)	R&R	3.62	3.57	2.58	18
Design, construction and material defects	Guo *et al*., (2016)	OC	3.33	3.85	2.56	19
Conflicts over land ownership	Macdonald and Cosham (2005)	PL	3.49	3.61	2.52	20
Threats to staff	Rowland (2010)	S&S	3.32	3.73	2.48	21
Public poverty and education level	Nnadi *et al*., (2014)	S&S	3.45	3.41	2.35	22
Operational errors	Nnadi *et al*., (2014)	OC	3.10	3.61	2.24	23
Inadequate risk management	Nnadi *et al*., (2014)	HSE	3.23	3.40	2.20	24
Leakage of sensitive information	Wu *et al*., (2015)	S&S	2.98	3.51	2.09	25
Geological risks	Guo *et al*., (2016)	PL	2.75	3.18	1.75	26
Natural disasters and weather conditions	Nnadi *et al*., (2014)	HSE	2.65	3.07	1.63	27
Vehicular accidents	Nnadi *et al*., (2014)	PL	2.46	2.71	1.33	28
Hacker attacks on the operating or control systems	Srivastava and Gupta (2010)	OC	2.24	2.97	1.33	29
Animal accidents	Mubin and Mubin (2008)	PL	1.89	2.02	0.76	30

^ For example RI for (Terrorism and sabotage) = (3.99 X 4.49)/5 = 3.58 (Sa'idi *et al*., 2014). * R means ranking.

Table 2: RMM classification and effectiveness.

RMMs (Hopkins *et al.*, 1999)	A	B	C	Effectiveness
Anti-corrosion measures such as isolation and cathodic protection		√	√	4.23
Move to an underground pipeline	√			4.07
Advanced technological and professional remote monitoring	√	√	√	4.0
Proper inspection, tests and maintenance			√	3.83
Proper training	√	√	√	3.79
Avoid insecure areas	√			3.78
Anti-terrorism design	√			3.78
Avoid registered risks and threats	√	√	√	3.77
Protective barriers and perimeter fencing	√	√	√	3.69
Government/public cooperation	√	√	√	3.57
Warning signs and marker tape above the pipeline		√	√	3.55
Foot and vehicle patrols		√	√	3.53

(A) Planning and design stage, (B) construction stage and (C) operation stage.

Figure 2 shows the suggested RMMs to mitigate the RFs in OGP projects in Iraq. The RMMs were ranked based on the survey results.

Risk factors	Direct Risk Mitigation Methods	Indirect risk mitigation methods
Terrorism & sabotage	Avoid the insecure areas	Use underground pipeline
Thieves	Anti-terrorism design	Government-public cooperation
Geographical location "insecure areas"	Protective barriers & perimeter fencing	Avoid the registered risks & threats
	Foot & vehicle patrols	Government-public cooperation
	High technology & professional remote monitoring	Anti-terrorism design
Public's low legal & moral awareness	Government-public cooperation	
Threats to staff	Foot & vehicle patrols	Avoid insecure areas
		Government-public cooperation
The pipeline is easy to access	Use underground pipeline	Avoid insecure areas
	High technology & professional remote monitoring	
	Protective barriers & perimeter fencing	
	Foot & vehicle patrols	
Geological risks such as groundwater & landslides	Anti-corrosion measures such as isolation and cathodic protection	Proper inspection, tests & maintenance
Vehicle accidents	Use underground pipeline	
	Protective barriers and perimeter fencing	
	Warning signs & marker tape above the pipeline	
Animal accidents on the pipeline	Use underground pipeline	
	Protective barriers & perimeter fencing	
Corrosion and lack of protection against it	Anti-corrosion measures such as isolation and cathodic protection	Proper inspection, tests & maintenance
Weak ability to identify & monitor the threats	High technology & professional remote monitoring	Proper inspection, tests & maintenance
	Avoid insecure areas	
		Proper training
		All methods
Shortage of IT services & modern equipment	High technology & professional remote monitoring	
Design, construction & material defects	Anti-corrosion measures such as isolation and cathodic protection	Proper training
	Anti-terrorism design	
	Avoid the registered risks & threats	
Operational errors	High technology & professional remote monitoring	Avoid the registered risks & threats
	Proper inspection, tests & maintenance	
	Proper training	
Lack of proper training	Proper training	

Figure 2: The suggested RMMs to mitigate the RFs.

By comparing Table 1 with Figure 2, we can see some RFs do not have any suggested RMMs. Therefore, in Figure 3, more RMMs which were not mentioned in the survey have been suggested to mitigate the first three RFs.

Risk factors	Suggested risk mitigation methods not from the survey
Improper safety regulations	Proper safety regulations
	Proper use of the risk mitigation methods
Hacker attacks on the operating or control system	IT Security
Conflicts over land ownership	Analyse the pipeline roots at the planning and design stages
Stakeholders are not paying proper attention	
Lack of historical and risk registration	
Few researchers are dealing with this problem	
Corruption	
The law does not apply to saboteurs and thieves	
Natural disasters and weather conditions	
Socio-political factors such as poverty and education level	
Leakage of sensitive information	

Figure 3: The suggested RMMs from outside the survey.

As some of the RFs shown in the above figure did not have any associated RMMs, it was necessary to identify more RMMs than those included in the survey (Figure 3). As suggesting RMMs for RFs like corruption is beyond the authors' knowledge, these RFs needed to come from very high levels of government.

The project stages were ranked regarding the priority for application of the RMMs by calculating the total response as follows. 1- Planning and design stage (with a total of 1.520); 2- construction stage (with a total of 2.045); 3- operation stage (with a total of 2.434). As 1 indicates the highest priority, the lowest total is the top rank. Fifty-eight out of 198 respondents chose aboveground as a comparatively safe pipeline network; while 140 respondents chose underground pipelines as the safer option to transport petroleum products in Iraq.

DISCUSSION

Risk management is a continuous process of identifying and analysing the RFs, risk response and risk control actions. Identifying the OGP RFs and RMMs based on a wide-ranging review provides accurate and appropriate knowledge about the safety of pipelines. Because there is no reference by which to analyse the risk factors and the risk mitigation methods, collecting information from various and trusted sources, i.e. government agencies, academic organisations and professionals (i.e. consultants, planners, designers, operators and researchers), ensures more verified analysis of OGP RFs and RMMs as the information has been gathered from field-experienced individuals. The respondents' demographic information enhanced the results because all the stakeholder categories were represented in the survey. Collecting stakeholder perceptions about OGP RFs and RMMs could reduce the time and the cost of investigations into OGP RFs. However, this method relies on their willingness to cooperate with the researchers, which is one of its disadvantages. Analysing and ranking the RFs and RMMs helps the stakeholders, decision-makers and policymakers to apply sustainable RMMs and risk management strategy during the different stages of pipeline projects.

Managing and mitigating the risk factors in these projects is not limited to one project stage. Therefore, different risk mitigation methods were suggested to mitigate the risk factors during the projects' entirety. Anti-corrosion measures such as isolation and cathodic protection were rated as an effective RMM because corrosion is one of the most common causes of OGP failure. The disadvantage of this method is that, in addition to the extra cost, it may slow down pipeline construction and installation processes as protections need to be applied. Applying advanced technological and professional remote monitoring (e.g. aerial and satellite surveillance, Global Positioning System (GPS) and smart camera systems) has some advantages, for example, surveying large areas of the pipeline network in a short period of time. The presence of these methods could serve as a deterrent against TPD, providing quick risk prediction and alerts, and these methods also offer the ability to exchange photos of the pipelines. However, these methods also have disadvantages including high capital investment for equipment, machinery and operational costs, and additional training for personnel on new software. Foot and vehicle patrols are less effective RMMs as they are very time consuming, do not cover large areas of the OGP network and need to be carried out at frequent intervals to be effective. That said, this method has some advantages like only requiring a moderate capital investment for equipment and machinery, and it is effective against TPD during inspection periods.

Ranking the RFs based on an RI method has some limitations. For example, the RF with a high RS value could be considered as a critical RF that needs urgent mitigation work. However, the same RF does not achieve a high rank if it has a low RP or vice versa. This means the RI method does not adequately reflect the criticality of the risks. This study has other limitations, such as the RMF cannot be used to link the RFs or draw OGP failure scenarios and calculate the consequences of any hazardous event. Also, it does not provide a decision support tool that has an automated system to analyse the information (e.g. RFs, RP, RS, RMMs and the effectiveness of RMMs).

The RMF could be applied to mitigate the RFs for other critical infrastructures like water supply network; transportation system (e.g. railway, high ways, fuel supply, etc.); energy supply infrastructure (e.g. transmission and distribution lines, nuclear power generators, etc.); telecommunication and communication facilities; etc. The RFs may be different in these projects, but insecure situations cause similar types of risks. Therefore, the methodology of identifying and evaluating the RFs and RMMs could be similar.

CONCLUSIONS

There is a need for an accurate evaluation of the RFs and RMMs in OGP projects, specifically regarding the issue of TPD, because they have not been accurately evaluated in the past. The proposed RMF provides a comprehensive and systematic risk management approach in OGP projects for organisations that have just begun to mitigate OGP RFs more effectively. In this paper, a new database has been created to store information about identifying and analysing the RF and RMMs.

While the survey results identified various problems and risks that cause pipeline failure, TPD (such as sabotage, corruption, insecure areas, lawlessness and theft) is recognised as one of the most common issues obstructing OGP projects in Iraq. In contrast, natural disasters and weather conditions, vehicle accidents, hacker attacks on the operating or control systems, and accidents involving animals are the RFs with the lowest impact on OGP projects in the country. Concerning risk mitigation, anti-corrosion measures such as isolation and cathodic protection, laying the pipes underground, and advanced technological and professional remote monitoring of the RFs are the most effective RMMs; foot and vehicle patrols prove less effective. The majority of participants agreed that moving pipelines underground is safer than having exposed ones. In addition, they said that the mitigation of the RFs in OGP projects should be started at the planning and design stage.

The future work of this study is as follows. 1- Use an Analytic Hierarchy Process (AHP) to compare the influential RFs. 2- Use a neural network analysis tool to draw some pipe failure scenarios to estimate the consequence. 3- Conduct some interviews with experts to analyse the cost-effects that result from applying the RMMs in OGP projects. 4- Use the Fuzzy Inference System (FIS) in the MATLAB toolbox to simulate the RFs as it is a powerful tool that deals with the uncertainty that results from the lack of data and experts' judgements. The paper's findings (RP, RS and risk ranking) will be used as inputs for the FIS. The expected outputs will be a useful viewing tool for looking at RF weight, the risk matrix and the overall safety of pipelines. 5- Use one of the decision support methods that can analyse the inputs (e.g. RFs, RP, RS, RMMs, the effectiveness of RMMs and the cost) to help the stakeholders during the decision-making process.

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