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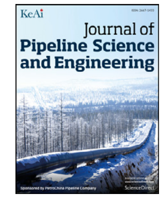

An investigation of mitigating the safety and security risks allied with oil and gas pipeline projects

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ABSTRACT

Oil and Gas Pipeline (OGP) projects face a wide range of safety and security Risk Factors (RFs) globally, particularly in the oil and gas producing countries having insecure environment and poor safety records. Inadequate information about the causes of pipeline failures and poor knowledge about the safety and the security of the OGP hinder efforts of mitigating such risks. This paper, therefore, aims to develop a risk management system that is based on a holistic approach of identifying, analysing and ranking the associated RFs, and evaluating the possible Risk Mitigation Methods (RMMs), which are the first steps of this approach. A qualitative document analysis was adopted to design a semi-structured industry-wide questionnaire, which was conducted to collect stakeholders' perceptions about existing RFs and RMMs for the OGP projects in Iraq. From the survey results, probability and severity levels of the RFs were used as inputs for a computer-based risk analysis model. The model used the fuzzy theory to judge the probability and consequence levels of the RFs and rank them with regards to their degree of impact in the projects. The results revealed that terrorism, official corruption and insecure areas are the most critical risks. Similarly, the RMMs were evaluated based on their degree of efficacy to mitigate the risk in OGP projects. This paper presents a prototype of the risk management system that will be further developed in the next stage of the study.

1. Introduction

Oil and Gas Pipelines (OGPs) provide a safe and economical mode that transports millions of barrels of petroleum products each day. However, despite OGPs being a safe mode of transportation for petroleum products, these projects are still subject to several threats that cause pipe failure if these threats are not effectively managed. For example, OGPs mainly suffer from Third-Party Disruption (TPD); corrosion; planning, design and construction defects; natural hazards; operational errors and unknown causes (Wan and Mita, 2010). OGP projects, therefore, must be planned, designed, installed, operated and maintained in ways that comply with safety and security requirements. This is because OGPs have a severe impact on people's lives and projects. Thus, the stakeholders of these projects must have a robust risk mitigation system that can keep the RFs at the lowest level, as far as possible.

Peng et al. (2016) define TPD as any accidental damage in OGPs occurring as a result of soil movement (e.g., landslides and foundation collapse); surface loads that compress pipelines (e.g., illegal building, blast construction and live ground loads); natural phenomena (e.g., earthquakes and floods); mechanical failures (e.g., operational errors and control system failures) and human activities near to pipelines (e.g., road construction, farming and drilling). In this paper, we classify these types of TPDs as unintentional TPDs. Muhlbauer (2004) suggested that TPD can also refer to any direct or indirect action that may be carried out individually, or by groups, to hinder the functionality of OGP systems such as terrorism, sabotage, theft and cyber-attacks on control systems. In this paper, we classify these types of TPDs as intentional TPDs.

Due to current, globally insecure environments, critical infrastructures like OGPs are potential targets for saboteurs. Correspondingly, TPD has been recognised as one of the most dominant mechanisms of OGP failure globally (Wan and Mita, 2010). Meanwhile, successful risk mitigation requires appropriate knowledge, an up-to-date database (Balfe, 2014) and accurate risk assessment regarding probability and severity levels of the Risk Factors (RFs), in order to identify the RFs which require prioritisation. Fang and Marle (2012) stated the process of risk management requires the following four steps.

(1) Risk identification and registration; which means identifying the RFs that might threaten OGPs based on verified recorders about OGPs, such as the records of pipelines' designs, surveillance, operational pressure, pressure test, maintenance, modification, inspections, maps of their routes, pipeline fault and accident causes (Hopkins et al., 1999).
(2) Risk analysis; which means assessing the RFs regarding their probability and severity levels (Kraidi et al., 2017). One of the problems in the existing methods of risk analysis is these methods are not ac-

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curate enough to analyse all the RFs, which is due to the absence of a historical database (Ge et al., 2015).

(3) Risk response; which means choosing the suitable Risk Mitigation Methods (RMMs) to mitigate the risk in OGP projects. Therefore, it is significant to evaluate the effectiveness of the RMMs.

(4) Risk monitoring and control; which is a continuing work-cycle of the previous steps to provide up-to-date information about the existing and new RFs and RMMs. However, existing risk evaluation methods are not accurate enough to calculate the probability of TPD RFs because a historical database has not yet been established (Kraidi et al., 2019a).

This research, therefore, aims to develop a holistic system of risk management that deals with managing the safety and the security of the OGP more effectively. Risk management systems are designed to provide appropriate knowledge, essential data, accurate analysis of RFs and an accurate evaluation of RMMs to help stakeholders successfully mitigate OGP risks.

This paper selected Iraq as the case study area because it is amongst the most important oil and gas producing countries in the world. Iraq's crude oil reserves are the world's fifth-largest (EIA, 2015), it's gas reserves ranging between the world's 10^{th} to 13^{th} largest reserves (IEA, 2013). Since 2003, there has been a high demand for more pipeline projects to meet the rapid increment in oil exports in Iraq (Moosa, 2013). However, a substantial range of RFs continuously affects these projects. Inadequacies regarding the management of such risk make pipeline failures inevitable, hindering oil export activities.

2. Literature review

2.1. Identification and classification of the RFs in OGP projects

With reference to Iraq, identifying the RFs in OGP projects is a challenging task due to the problem of the scarcity of data and the lack of information about the causes of pipeline failure and RMMs. Therefore, worldwide qualitative document analyses was carried out to provide a wide and in-depth review about RFs and RMMs in OGP projects, specifically in insecure environments. The review about the RFs and RMMs in OGP projects will help to identify the critical RFs and the commonly used RMMs in OGP projects in a way that contributes to overcoming the problem of the scarcity of data and the lack of information about them. For instant, Nnadi et al. (2014) found that there are many RFs that are affecting the safety and the security of OGPs in Nigeria. Such as terrorism and sabotage attacks; official corruption; thieves; corrosion and lack of protection against it; improper inspection and maintenance; weak ability to identify and monitor the risks; stakeholders not paying proper attention; lack of proper training, shortage of modern IT services; limited warning signs; lack of risk registration; little research on this topic; public poverty and education level; operational errors; inadequate risk management; natural disasters and weather condition.

Moreover, Rowland (2010) explained the exposed pipelines (i.e., above ground pipelines) and threats to staff are effacing the safety and security of OGPs in Nigeria. Srivastava and Gupta (2010) draw a scenario about a terrorist attack that might happen in India and they expect RFs like insecure areas, easy access to pipeline and hacker attacks on the operating or control systems might affect OGPs in their country. Other studies added more RFs like lawlessness, low public legal and moral awareness, and vehicular accidents (Shen et al., 2016), improper safety regulations; design, construction and material defects and geological risks (Guo et al., 2016), conflicts over land ownership (Macdonald and Cosham, 2005), leakage of sensitive information (Wu et al., 2015), and animal accidents (Mubin and Mubin, 2008). Table 1 below summarises the findings of the literature review with regards to identifying the RFs that affect the safety and security of OGP projects in different countries, circumstances and environments worldwide.

Table 1
The findings of the literature review, the identified RFs (Kraidi et al., 2019).

RFs	Circumstances
Terrorism & sabotage	The pipeline is easy to access
Corruption	Limited warning signs
Low public legal & moral awareness	Little research on this topic
Insecure areas	Lawlessness
Thieves	Stakeholders are not paying proper attention
Corrosion & lack of protection against it	Public's poverty & education level
Lack of proper training	Inadequate risk management methods
Improper safety regulations	Leakage of sensitive information
Exposed pipelines	Threats to staff (kidnap or murder)
Improper inspection & maintenance	Operational errors e.g., human error and equipment failure
Conflicts over land ownership	Geological risks like soil movement and landslides
Shortage of the IT services & modern equipment	Natural disasters & weather conditions
Weak ability to identify & monitor the threats	Hacker attacks on the operating or control system
Design, construction & material defects	Vehicle accidents
Lack of historical records about accidents and risk registration	Animal accidents

The RFs identified in this paper were classified into different groups based on their types. Several prior studies were found to be useful when classifying the RFs in the OGP projects. Mubin and Manna (2013) classified the RFs that affected the safety of the pipeline projects in Pakistan during the construction and operation stages into seven types: socio-economic, technical, natural catastrophic, organizational, financial, environmental, and safety and security RFs. El-Abbasy et al. (2016) classified the factors affecting pipeline conditions into three main groups, namely physical factors (e.g., pipes, age, diameter, metal loss and coating conditions); operational factors (e.g., corrosion, operating pressure and flow rate); and external RFs resulting from the environment surrounding the OGPs (e.g., traffic, weather conditions, TPD and soil properties). However, these classifications of OGP RFs were broad and need to be more specific. Chen et al. (2021) divided the research about pipeline safety into six parts: technical safety issues, human error/human factors, management focus on HSE, safety management systems, safety culture, and knowledge management/communication safety. To cover RFs that are affecting the OGP projects at all stages, we have classified the identified RFs according to their risk characteristics into five different groups, including Security and Societal (S & S); Pipeline Location (PL); Health, Safety and Environment (HSE); Operational Constraints (OC) and Rules and Regulations (R & R), as presented in Table 2.

2.2. Identification and classification the RMMs in OGP projects

In order to make some suggestions about managing the RFs in OGP projects in Iraq, the investigations of the literature review were extended to identify some of the RMMs which are used to manage the RFs in OGP projects in different countries and geographical regions. The RMMs were classified according to project stages, depending on an estimate of when these RMMs could be applied during the project stages as follows: planning and design; construction; and operation and maintenance stages (Table 3).

The RMMs mentioned in the above table are some of the methods used to manage the RFs in OGP projects from around the world and identified in the literature review. The investigations about the RMMs in OGP projects will make the findings of this research suitable for and applicable to many countries as the RMMS were identified from OGP projects in different countries and environments. In addition, these methods will be used to make effective suggestions about risk management in OGP projects in Iraq.

Table 2
The classification of the RFs in OGP projects in Iraq by their types (Kraidi et al., 2019a; Kraidi et al., 2020; Kraidi et al., 2019b; Kraidi et al., 2019c; Kraidi et al., 2018).

RFs	Risk type (Kraidi et al., 2019a)
Terrorism & sabotage	Security & Social (S & S)
Low public legal & moral awareness	
Thieves	
Public's poverty & education level	
Leakage of sensitive information	
Threats to staff (kidnap or murder)	
Corruption	Rules and Regulations (R & R)
Lawlessness	
Stakeholders are not paying proper attention	
Lack of proper training	
Lack of historical records about accidents and risk registration	
Little research on this topic	
Insecure areas	Pipeline Location (PL)
The pipeline is easy to access	
Conflicts over land ownership	
Geological risks like soil movement and landslides	
Vehicle accidents	
Animal accidents	
Corrosion & lack of protection against it	Operational Constraints (OC)
Weak ability to identify & monitor the threats	
Shortage of the IT services & modern equipment	
Design, construction & material defects	
Operational errors e.g., human error and equipment failure	
Hacker attacks on the operating or control system	
Improper safety regulations	Health, Safety and Environment (HSE)
Exposed pipelines	
Improper inspection & maintenance	
Limited warning signs	
Inadequate risk management methods	
Natural disasters & weather conditions	

The identified RFs (Table 1) and RMMs (Table 3) in OGP projects will be used to design an industrial survey in order to test their degree of impact in OGP projects in Iraq.

2.3. Risk analysis in OGP projects

This section of the paper reviews some of the prior studies that researched into risk analysis and management in OGP projects in different countries and regions. For example, Mubin and Mubin (2008) developed a risk management model for OGPs in Pakistan during the construction stage of the projects. In that model, the authors have shown the process of risk identification and classification based on the analysis of the local market and the review of the client and contractors. The authors used Monte Carlo simulation to assess the RFs and rank them based on their degree of impact on the projects. The final step of the model was about developing a data bank and proving recommendations for the risk management process. Schwarz et al. (2015) proposed a risk management procedure to support decision-making processes in projects. The authors started their model by defining the project's scope and the criteria of risk management and identifying the RFs. Then, the Artificial Neural Network (ANN) was used with experts' judgment to analysis and rank the RFs. The final step of the model was about evaluating the RFs and supporting the decision-makers. El-Abbasy et al. (2015, 2016) carried out similar work in order to assess the conditions of the OGP network in Canada and Qatar. Simlarley, 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 in these projects.

The studies that are mentioned in the above paragraphs would not be effective to manage the RFs in OGP projects elsewhere because of the following gaps in knowledge.

(1) The findings of these studies are based on only a local review of identifying the RFs in the projects, while the types and characters of the RFs that affect the safety and security of the projects in other countries or geographical regions are different.
(2) These studies used the available databases to identify the RFs in the projects. However, the lack of data about the RFs in these projects means the existing models are not effectively applicable elsewhere, particularly in developing countries. This is because available databases are lacking in RFs that affect the safety and security of OGP projects in developing countries. Often there is a lack of documentation and there are no appropriate records about the accidents in the projects.
(3) These studies are limited to analysing the RFs during the operation stage of OGP projects. Meanwhile, there is an enormous number of RFs that affect the safety and security of the projects during the planning, design and construction stages too.
(4) These studies have not tried to overcome the uncertainty that results from analysing the RFs based only on the experts' judgments. This means that the results of risk analysis of these frameworks have a low-reliability level.

2.4. Using fuzzy theory in risk analysis in OGP projects

Khan et al. (2015) made a comparison between the methods and models used in risk management, explaining that: "Similar to any other quantification, quantification associated with inherent safety assessment may also contain a certain extent of uncertainty. A fuzzy logic based method was developed to produce a more realistic estimation reducing the uncertainty associated with subjective analysis". The section focuses on reviewing a number of past studies that used fuzzy theory to analyse the TPD RFs in the oil and gas industry because they are related to the scope of this research.

Li et al. (2019) analysed the precursor data and used the fuzzy theory to analyse and assess the RFs in the subsea OGPs. Using the fuzzy theory has helped to reduce the uncertainty associated with analysing the impact of the RFs on the projects using the qualitative analysis of

Table 3
The identified RMMs in the OGP projects based on the literature review (Kraidi, 2020).

RMMs	Planning & design stage	Construction stage	Operation & maintenance stage
Anti-corrosion such as isolation & cathodic protection		√	√
Move to an underground pipeline	√		
Advanced technological & professional remote monitoring	√	√	√
Proper inspection, tests & maintenance			√
Proper training	√	√	√
Avoid insecure areas	√		
Anti-terrorism design	√	√	√
Avoid registered risks & threats	√	√	√
Protective barriers & perimeter fencing	√	√	√
Government/public cooperation	√	√	√
Warning signs & marker tape above the pipeline		√	

the precursor documents only. Cheliyan and Bhattacharyya (2018) and Arzaghi et al. (2018) used the fuzzy fault tree to analyse the leakage risk in OGP subsea production systems. However, all of these research studies did not make suggestions for risk management in the projects.

Urbina and Aoyama (2017) used fuzzy theory to reduce the uncertainty associated with determining the cost of risk management activities in pipeline projects and the probability and the severity levels of the hazard events in these projects. Innal et al. (2016) tried to reduce the uncertainty in safety-instrumented systems using fuzzy theory and Monte Carlo analysis. Keprate and Ratnayake (2016) used fuzzy theory to select the best locations for fatigue-critical piping locations for inspection of offshore pipelines. Lu et al. (2015) study used fuzzy theory to calculate the probability of failure for underwater gas pipeline projects undertaken by the China National Petroleum Corporation (CNPC). Peng et al. (2016) used fuzzy theory to assess the TPD in OGP projects in PetroChina Gang-Zao. Fuzzy theory has enhanced the results of analysing the probability of accidents and the RFs. Guo et al. (2018) analysed some of the leakage accidents occurring in OGPs in China. This study used fuzzy theory and Bayesian theory to overcome the problem of defining the boundaries of the RFs while analysing them in the pipeline projects.

Jamshidi et al. (2013) provided a systematic risk assessment framework to analyse the RFs in gas pipeline projects in Iran. This study used fuzzy theory as a rational way of coming up with precise and robust results of risk analysis. The authors suggested performing more quantitative analyses about the RFs (e.g., questionnaire survey and experts' judgements) in order to provide accurate inputs for their study before using fuzzy theory to analyse the RFs. In doing so, fuzzy theory will provide a better prediction about the probability and severity levels of the RFs in the projects.

Zhang et al. (2016) developed a framework in order to evaluate the performance of a petroleum transportation system. The framework identified and evaluated the RFs via the literature review and a questionnaire survey. It used linguistic evaluation and fuzzy theory to reduce the complexity and uncertainty involved with risk analyses using experts' judgements. However, this study evaluated the RFs based on ambiguous features and subjective perception, which means this study needs further research with regard to providing dynamic data and effective mathematical algorithms and calculations to provide more trusted inputs for the study.

In this study, therefore, used the fuzzy theory in the process of the risk assessment in order to reduce the problems relating to the uncertainty of analysing and ranking the RFs based on the results of the survey only.

3. Research methodology

This study has using a mixed methodology to analyse and rank the RFs and RMMs in OGP projects. Fig. 1 shows the milestones and the key stages information of this study.

The qualitative approach of this study involved identifying the RFs and RMMs in OGP projects based on the qualitative analysis of the literature review. The findings of the literature review, i.e., the identified RFs and RMMS were used to design a questionnaire survey, which was used to understand the stakeholders' perceptions about the "probability and severity" levels of the RFs and the "effectiveness" levels of RMMs.

The quantitative part of this study is about using the results of the survey to rank the RFs regarding their degree of influence on OGP projects, i.e., the value of Risk Index (RI) for each RF. However, ranking the RFs based only on the results of the survey has some limitations of reflecting an accurate ranking of the RFs. Perhaps an RF has a high severity value, which means this RF needs urgent mitigation work before it threatens the projects. However, the same RF will not appear on a high rank if its' probability is low, and vice versa. Moreover, as Kraidi et al. (El-Abbasy et al., 2014; Khan et al., 2015; Li et al., 2019; Urbina and Aoyama, 2017) concluded, uncertainty could arise during risk analysis due to data scarcity or incomplete information about the RFs and experts' judgments about them. In such a situation, the fuzzy theory is a useful tool that can be employed to handle risk analysis when there are no precise values and sharp boundaries (Biezma et al., 2018). Because fuzzy logic uses expressions and linguistic labels instead of rigid mathematical rules and equations to model the behaviour of a system or sub-system (Yazdani-Chamzini, 2014). Therefore, this study has used the fuzzy theory to analyse and rank the RFs in OGP projects.

3.1. Questionnaire design

In conditions of data scarcity, the RFs will be mainly identified based on the literature review. The impact of the identified RFs will be assessed based on stakeholders' judgements as they have real experience about them in their projects (Miri Lavasani et al., 2011; Sa'idi et al., 2014). This research, therefore, seeks to engage with stakeholders who have a better understanding of the oil and gas industry and have a piece of real knowledge about the problems, risks and challenges associated with OGPs. Most importantly, the survey aims to obtain consensus views and perceptions from the relevant stakeholders in a way that reflects the reality of the RFs in OGP projects.

The questionnaire survey is one of the most widely used research methods for data collection, which helps in engaging with respondents or participants in the survey who are eager to engage and understand

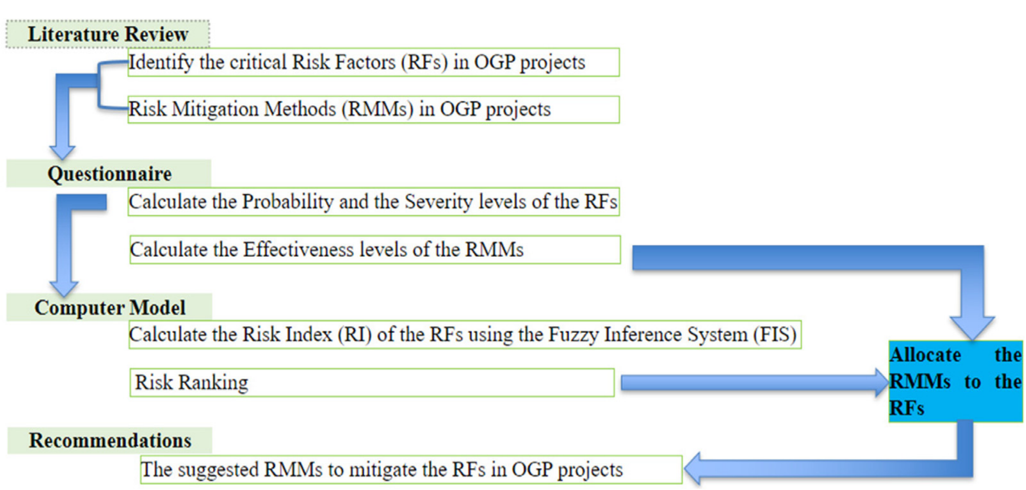

Fig. 1. The milestones and the key stages information of this study.

Table 4
The probability and severity levels of the RFs in OGP projects in Iraq based on the results of the survey (Kraidi et al., 2019a; Kraidi et al., 2020; Kraidi et al., 2019b; Kraidi et al., 2019c; , Kraidi et al., 2018).

RFs	RP	RS
Terrorism & sabotage	3.995	4.490
Corruption	3.980	4.323
Low public legal & moral awareness	3.712	4.106
Insecure areas	3.717	4.192
Thieves	3.692	4.081
Corrosion & lack of protection against it	3.687	3.990
Lack of proper training	3.646	3.859
Improper safety regulations	3.687	3.960
Exposed pipelines	3.667	3.949
Improper inspection & maintenance	3.657	3.899
Conflicts over land ownership	3.495	3.646
Shortage of the IT services & modern equipment	3.667	3.924
Weak ability to identify & monitor the threats	3.631	3.848
Design, construction & material defects	3.333	3.611
Lack of historical records about accidents and risk registration	3.566	3.662
The pipeline is easy to access	3.631	3.773
Limited warning signs	3.626	3.732
Little research on this topic	3.621	3.697
Lawlessness	3.606	3.682
Stakeholders are not paying proper attention	3.530	3.652
Public's poverty & education level	3.449	3.611
Inadequate risk management methods	3.227	3.505
Leakage of sensitive information	2.980	3.399
Threats to staff (kidnap or murder)	3.323	3.571
Operational errors e.g. human error and equipment failure	3.101	3.409
Geological risks like soil movement and landslides	2.747	3.182
Natural disasters & weather conditions	2.652	3.066
Hacker attacks on the operating or control system	3.066	3.066
Vehicle accidents	2.465	2.970
Animal accidents	1.894	2.020

an attitude or a behaviour of a certain phenomenon (Creswell and Creswell, 2017). In other words, the questionnaire is commonly used to ask participants questions prepared by the researcher(s) (i.e., the surveyor(s)) to collect baseline data to be used for analysing a certain phenomenon later on P.E.T.C.P. (2020). A previous study by Alali (2010) found that around 61% of the research studies in the field of project management normally used surveys and questionnaires to collect research data for their studies. They are also used to collect desirable research data from the participants/stakeholders which might be unavailable elsewhere (Fowler Jr and Cosenza, 2009). Thus, the questionnaire survey is utilised in this research to collect the primary research data about the probability and severity impact of the RFs and the potentially effective RMMs in the OGP projects based on the perceptions of the relevant stakeholders.

A pilot survey was carried out to improve the clarity of the questions and revise ambiguous ones before distributing the final survey (Kraidi et al., 2018). The snowball sampling technique for data collection was used to ensure the widespread distribution of the survey (Innal et al., 2016). The participants were assured that their participation would be analysed confidentially.

In the survey, the probability levels of the RFs were identified based on a scale of (1) = rare, (2) = unlikely, (3) = possible, (4) = likely and (5) = almost certain. Similarly, the severity levels of RFs were evaluated based on a scale of (1) = negligible, (2) = minor, (3) = moderate, (4) = major and (5) = catastrophic. To determine the values of Risk Probability (RP) and Risk Severity (RS) of each RF, the means of the five-point rating Likert scale responses were calculated. The results of RP and RS of the RFs are presented in Table 4.

In the survey, the effectiveness levels of RMMs were evaluated based on a scale of (1) = insignificant, (2) = slightly effective, (3) = moderately effective, (4) = very effective and (5) = extremely effective. To determine the values of the effectiveness levels of the RMMs, the means of the five-point rating Likert scale responses were calculated. Table 5 explains the degree of efficacy of RMMs based on the results of the survey.

Table 5
The effectiveness levels of the RMMs based on the results of the survey.

RMMs	The effectiveness levels of the RMMs
Anti-corrosion such as isolation & cathodic protection	4.23
Move to an underground pipeline	4.07
Advanced technological & professional remote monitoring	4.00
Proper inspection, tests & maintenance	3.83
Proper training	3.79
Avoid insecure areas	3.78
Anti-terrorism design	3.78
Avoid registered risks & threats	3.77
Protective barriers & perimeter fencing	3.69
Government/public cooperation	3.57
Warning signs & marker tape above the pipeline	3.55
Foot & vehicle patrols	3.53

As shown in Table 5, based on the perceptions of the stakeholders in OGP projects that were collected from the survey, the results of evaluating the effectiveness degree of the RMMs show that anti-corrosion measures, moving to an underground pipeline, and the use of high technology and professional remote monitoring are the most effective RMMs.

Corrosion could be protected against by providing the pipelines with an external coating, using isolation layers, a cathodic protection system, or a combination of these methods. However, these methods are not perfect. Therefore, the condition of the coating, the isolation layers, and the system of cathodic protection must be periodically checked for any issues (Kraidi, 2020; Kraidi et al., 2018). The main disadvantage of this method is the added cost to the projects, and it might slow down pipeline construction and installation processes as certain protections need to be applied.

Regular risk monitoring and surveys by using advanced technological and professional remote monitoring (e.g., aerial and satellite surveillance, remotely controlled vehicles, Global Positioning System (GPS), and smart camera systems) can help to investigate any unauthorised activities in OGP project zones such as terrorism, sabotage, thievery, illegal excavation, and construction activities near to the pipeline. Using these methods has a number of advantages, for example, surveying a large network of pipelines in a short period of time. The presence of these methods could serve as a deterrent against intentional TPD and provide quick risk prediction and alerts. These methods also enable photographs of pipelines to be shared between the project partners. However, they also have disadvantages including high capital investment for equipment and machinery, operational costs, and additional training for personnel on new software.

Based on the survey results, foot and vehicle patrols are not effective RMMs as they are 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 such as requiring a moderate capital investment for equipment and machinery, and it is effective against intentional or unintentional TPD during inspection periods.

Proper operational practices, inspections and maintenance reduce operative RFs and mechanical failure for the pipeline. Most operators in OGP projects control operational RFs by limiting the operational stress (operating pressure) and following the regulations and codes. However, Kraidi (2020) and Kraidi et al. (2018) noticed some problems with such a procedure: (i) the regulations and codes are different in different areas and companies; therefore, they are not applicable to OGPs everywhere; (ii) this procedure might potentially miss new RFs if risk identification and registration process are not up to date; and (iii) this procedure creates an inflexible practice of risk management that restricts the stakeholders in applying new methods of identifying and mitigating the RFs.

The landowners and construction workers should monitor pipelines in their areas to avoid carrying out farming or construction work that could damage the pipes. Providing communication facilities for the local population such as emergency contact (emails and phone numbers) and phone lines, mailboxes, and so forth) could help people to report any threat to a pipeline. Iraq's OGP network is above ground, which means that the pipelines are susceptible to RFs mainly related to TPD.

Laying the pipelines underground is also an effective RMM, this is because the pipelines will not be easily seen or accessed by vandals and the pipelines will not be subjected to vehicular accidents or risk.

On the other side, it was found that foot and vehicle patrols are not effective RMMs as they are 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 such as requiring a moderate capital investment for equipment and machinery, and it is effective against intentional or unintentional TPD during inspection periods. Proper operational practices, inspections and maintenance reduce operative RFs and mechanical failure for the pipeline. Most operators in OGP projects control operational RFs by limiting the operational stress (operating pressure) and following the regulations and codes. However, Hopkins et al. (1999) noticed some problems with such a procedure: (i) the regulations and codes are different in different areas and companies; therefore, they are not applicable to OGPs everywhere; (ii) this procedure might potentially miss new RFs if RF identification and registration are not up to date; and (iii) this procedure creates an inflexible practice of risk management that restricts the stakeholders in applying new methods of identifying and mitigating the RFs. The landowners and construction workers should monitor pipelines in their areas to avoid carrying out farming or construction work that could damage the pipes. Providing communication facilities for the local population such as emergency contact details (emails and phone numbers) and phone lines, mailboxes and so forth, could help people to report any threat to a pipeline. Iraq's OGP network is above ground, which means that the pipelines are susceptible to RFs mainly related to TPD.

3.2. Analyse and rank the RFs using the fuzzy theory

Analysing the RFs using the Fuzzy Inference System (FIS) toolbox in MATLAB has three stages, which are fuzzification, knowledgebase, and defuzzification (see Fig. 2). (I) Fuzzification provides crisp inputs for the FIS. Step II of risk management 'risk analyses' means assessing the RFs regarding their probability and severity levels. Therefore, RP and RS are the two required inputs for the FIS in this paper (see Fig. 3). (II) Knowledgebase defines the membership functions for the inputs and

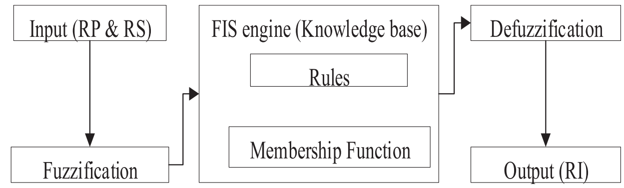

Fig. 2. The prototype computer-based risk simulation model using FIS (Sa'idi et al., 2014).

outputs of the model (see Figs. 3 and 4) and the 'If-Then rules' to control the FIS. (III) Defuzzification is about obtaining the final outputs of the model, which is RI in this model. In this stage of the FIS, the value of the RI will be calculated for the RFs depending on the range of RP and RS of each RF and the controlling rules of the model (see Figs. 3 and 4).

To summarize this section, the model has 60 inputs data, which are 30 RP and 30 RS for the 30 RFs; and 30 outputs, which are 30 RI for the 30 RFs. Finally, in order to highlight the most critical RFs in OGP projects, the RFs will be ranked regarding their values of RI because they judge both the probability and severity of each factor, see Table 6.

The ranking of the RFs as shown in Table 6 indicated that terrorism and sabotage, corruption, low public legal and moral awareness, insecure areas, and theft are the most critical RFs. In contrast, natural disasters and weather conditions, hacker attacks on the operating or control systems, and accidents involving vehicles and animals are the RFs with the lowest impact on OGPs.

4. Results

4.1. Response rate

The questionnaire survey was sent to 400 potential participants. The response rate was 49.5% since 198 participants responded. The response rate in this research was high compared to past studies. For instance, Bennett and Nair (2010); and Nair (2013) put the average response rate for online surveys at about 30% to 36%, which means the response rate in this research is more than the expected rate. This rate is good compared to Okaro (2017) with a response rate of 33% and 82 participants, and Rowland (2010) with a response rate of 23% and 151 participants.

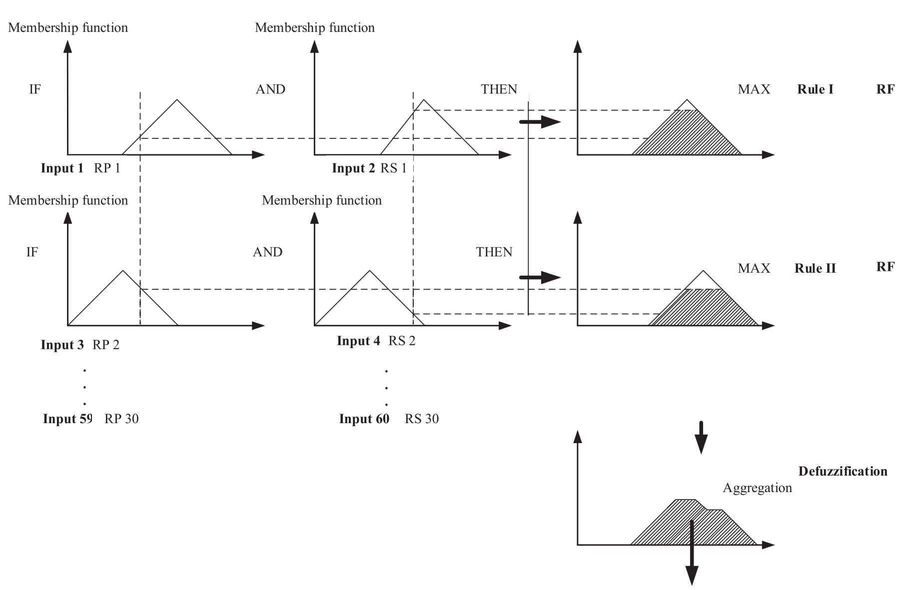

Fig. 3. The Min-Max membership function of the FIS (Zadeh, 1965).

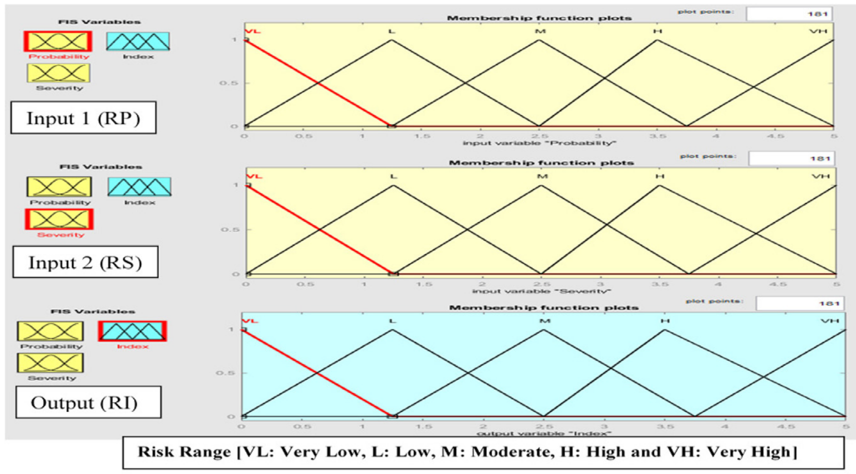

Fig. 4. Triangular fuzzy membership functions.

Table 6
The ranking of the RFs based on the results of the fuzzy theory.

RFs	Index	Rank	Risk range*
Terrorism and sabotage	3.99	1	H
Corruption	3.87	2	H
Low public legal and moral awareness	3.80	3	H
Insecure areas	3.76	4	H
Thieves	3.75	5	H
Corrosion and lack of protection against it	3.72	6	H
Lack of proper training	3.71	7	H
Improper safety regulations	3.70	8	H
Exposed pipelines	3.70	9	H
Improper inspection and maintenance	3.69	10	H
Conflicts over land ownership	3.68	11	H
Shortage of IT services and modern equipment	3.68	12	H
Weak ability to identify and monitor the risks	3.67	13	H
Design, construction and material defects	3.64	14	H
Lack of risk registration	3.60	15	H
Easy access to pipeline	3.57	16	H
Limited warning signs	3.56	17	H
Little research on this topic	3.55	18	H
Lawlessness	3.54	19	H
Stakeholders not paying proper attention	3.51	20	H
Public poverty and education level	3.49	21	H
Inadequate risk management	3.48	22	H
Leakage of sensitive information	3.38	23	H
Threats to staff	3.35	24	H
Operational errors	3.30	25	H
Geological risks	3.17	26	H
Natural disasters and weather conditions	3.10	27	H
Hacker attacks on the operating or control systems	3.03	28	H
Vehicular accidents	2.80	29	M
Animal accidents	1.95	30	L

* Risk range, Very Low (VL)= [0–1], Low (L)= [1–2], Moderate (M)= [2–3], High (H)= [3–4] and Very High (VH)= [4–5].

4.2. The demographic information of the participants

According to the participants' occupations, as recorded in the survey, 14 participants were consultants, planners or designers, 71 were members of construction teams, which means executive engineers, 41 were operators, 39 were owners or clients, and 33 were either researchers or postgraduate students associated with the OGP projects. The students are employed in the OGP projects and at the same time studying for their master's or PhD, which means they have experience of working on these projects. In terms of participants' experience, 74 have between one and 5 years of experience in OGP projects, 67 have 5 to 10 years, 29 participants have 10 to 15 years, and 28 of them have more than 15 years of experience. In respect of the participants' education, 3 of them were vocational or crafts-based, 28 have a high school or a diploma degree, 106 have a bachelor's degree (engineers), and 61 have a master's or a PhD degree. The appropriate sampling of the targeted population Table 7 enhances the results of this research because all the stakeholder categories during all stages of a project were represented in the survey.

4.3. The reliability level of the survey

Cronbach's alpha correlation coefficient (α) (Table 7) was calculated to test the level of reliability of the survey and the average internal consistency of survey items (Webb et al., 2006) where a coefficient of 0.7 indicates a minimum level of reliability (Pallant, 2001). Cronbach's alpha is not applicable for the first three questions asked for demographic information of the participants.

4.4. The suggested RMMs

Managing and mitigating the risk factors in these OGP projects is not limited to one stage of the project. Therefore, different risk mitigation methods were suggested to mitigate the risk during the project's entirety. Based on the survey results, anti-corrosion measures such as isolation and cathodic protection were rated as effective RMMs.

Depending on the character of the risk factor, a number of RMMs were suggested to manage each one of the RFs. 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 with minimising the opportunities for terrorists and saboteurs to attack them. However, terrorists and vandals still have an opportunity to damage the pipelines. Educating government/public corporations about managing the safety of OGPs and reporting any case of vandalism could 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 RMM(s) in the way that the RMM(s) will mitigate the RFs. In a case where the RF has more than one RMM to manage it, the RMMs were ranked based on their degrees of effectiveness that were collected via the survey. Table 8 illustrates the suggested RMMs in order to mitigate the risk in OGP projects.

5. Discussions

The comprehensive review of literature suggested a list of RFs and a list of RMMs associated with the OGP projects in different countries across the world. Identifying OGP RFs and RMMs based on a wide-ranging review provides accurate and appropriate knowledge about the safety and security of pipelines. Collecting information from various and trusted sources i.e., government agencies, academic organisations and

Table 7
The case processing summary of Cronbach's alpha correlation coefficient (α).

Case processing summary	No. of samples	Excluded	Valid %	α
The whole questionnaire	198	0	100	0.910
The question of analysing the RP of the RFs	198	0	100	0.919
The question of analysing the RS of the RFs	198	0	100	0.863
The question of analysing the effectiveness levels of the RMMs	198	0	100	0.792

Table 8
The suggested RMMs in order to mitigate the risk in OGP projects.

	The suggested RMMs	
RFs	The RMMs that have a direct action to manage the RFs	The RMMs that have an indirect action to manage the RFs
(1) Terrorism, sabotage and the security (2) Theft of the products (3) Insecure areas	(1) Avoid the insecure areas. (2) Anti-terrorism design. (3) Use protective barriers and perimeter fencing (4) Use a high technology and advanced risk-monitoring system. (5) Government-public cooperation. (6) Foot and vehicle patrols. (7) Use the rivers and lakes to extend the pipelines in the insecure areas despite the construction cost and the risk of corrosion.	(1) Use underground pipeline. (2) Expand the protection zones along with the pipelines and remove the random buildings and unauthorised activities in the pipeline production zones.
Public's low legal and moral awareness	Government-public cooperation	1 Use protective barriers and perimeter fencing. 2 Expand the protection zones along with the pipelines and remove the random buildings and unauthorised activities in the pipeline production zones.
Threats to staff	1 Avoid insecure areas. 2 Foot and vehicle patrols.	Government-public cooperation
The pipeline is easy to access	1 Use underground pipeline. 2 Use a high-technology and advanced risk-monitoring system. 3 Use protective barriers and perimeter fencing. 4 Foot and vehicle patrols. 5 Expand the protection zones along with the pipelines. 6 Use the rivers and lakes to extend the pipelines in the insecure areas.	Avoid insecure areas
Geological risks such as groundwater and landslides	1 Anti-corrosion such as isolation and cathodic protection. 2 Extend the pipes inside concrete pipes.	Proper inspection, tests and maintenance
Vehicle accidents	1 Use underground pipeline. 2 Use protective barriers and perimeter fencing. 3 Warning signs. 4 Choose the pipeline routes accurately to avoid the traffic areas.	Expand the protection zones
Animal accidents on the pipeline	1 Use underground pipeline. 2 Use protective barriers and perimeter fencing.	Expand the protection zones
Corrosion and lack of protection against it	1 Anti-corrosion such as isolation & cathodic protection. 2 Extend the pipes inside concrete pipes. 3 Use optimisers and remove the salts and metals before pumping the petroleum products. 4 Pump only one type of product in the pipeline and use a different pipeline for each oil field.	1 Proper inspection, tests and maintenance. 2 Use high-quality pipes and spare parts. 3 Do not use pipes older than the design age.
The weak ability to identify and monitor the threats	1 Use a high-technology and advanced risk-monitoring system. 2 Proper inspection, tests and maintenance. 3 Proper training. 4 Record pipeline accidents and risks in order to avoid them in the future.	All of the RMMs could be used to improve the ability to identify and monitor the RFs in OGP projects
Shortage of the IT services and modern equipment	Use a high-technology and advanced risk-monitoring system	
Design, construction and material defects	1 Proper training. 2 Make studies about the safety of the pipelines and follow the new research about risk management. 3 Use high-quality pipes and spare parts. 4 Choose well-known design companies to minimise design errors. 5 Choose well-known construction companies to minimise construction defects.	Do not use pipes older than the design age.

(*continued on next page*)

Table 8 (*continued*)

RFs	The suggested RMMs	
	The RMMs that have a direct action to manage the RFs	The RMMs that have an indirect action to manage the RFs
Operational errors	1 Choose well-known construction companies to minimise construction defects. 2 Commit to the operating standards. (e.g. do not pass the design capacity). 3 Use optimisers and remove the salts and metals before pumping the petroleum products. 4 Pump only one type of product in the pipeline and use a different pipeline for each oil field.	All of the RMMs could be used to manage the RFs in OGP projects during the operation stage.
Lack of appropriate training	Proper training	Record pipeline accidents and risks in order to avoid them in the future
Conflicts over land ownership	(1) Choose the pipeline routes accurately to avoid conflicts over land ownership (2) Taking future urban planning into account	
Salt and metal contents in the transported products such as silver	Use optimisers and remove the salts and metals before pumping the petroleum products	
The pipes are older than the design age	Do not use pipes older than the design age	
Not taking the future urban planning into account	Taking future urban planning into account	
Poor quality pipes	Use high-quality pipes and spare parts	
Natural disasters and weather conditions	Choose the pipeline routes accurately to avoid natural disasters	
Few researchers are dealing with this problem	Make studies about the safety of the pipelines and follow the new research about risk management	
Lack of risk registration	Record pipeline accidents and risks in order to avoid them in the future	
Not paying appropriate attention to risk management (e.g., not following scheduled programmes to solve problems)	1 The stakeholders in different levels should pay the appropriate attention to the risk management in their projects. 2 Follow and commit to the operating standards (e.g. do not pass the design capacity).	
Improper inspection and maintenance	Proper inspection, tests and maintenance	
Improper safety regulations	All the methods	
The aboveground pipelines increase sabotage and theft opportunities, as they are easy to access	1 Move to an underground pipeline. 2 Foot and vehicle patrols. 3 Use the rivers and lakes to extend the pipelines in the insecure areas despite the construction cost and the risk of corrosion.	1 Use a high technology and advanced risk-monitoring system. 2 Use protective barriers and perimeter fencing. 3 Warning signs and marker tape above the pipeline 4 Expand the protection zones along with the pipelines and remove the random buildings and unauthorised activities in the production zones of the pipeline.
Limited warning signs	Warning signs and marker tape above the pipeline	
Inadequate risk management	All the methods	
Pumping more than one type of petroleum product and crude oil from different fields in the same pipe	Pump only one type of product in the pipeline and use a different pipeline for each oil field	

professionals (e.g., consultants, planners, designers, operators and researchers) will provide ‘real’ information for future pipeline risk management. This also ensures a more accurate and reliable analysis of OGP RFs and RMMs as the information has been gathered by field-experienced individuals. The survey results were found to be reliable as all α values are above 0.7 (Table 7), an appropriate sampling of the targeted population enhancing the results.

Using the fuzzy theory to analyse the RFs in the project could be improved by paying more attention towards the fact that the fuzzy theory-based expert system applies an imprecise term that could lead to poor performance in many situations, where identifying the risk level of OGP stations includes many overlapping variables changing over time. This does not really assess the risk level in such big projects and can affect decision-making as well as the validity and reliability of decisions made by such systems. Consequently, we recommend taking a step forward and considering sophisticated, intelligent approaches to identify the risk levels of such big projects. The next stage of the research is to apply a set of machine learning algorithms to link the RFs in OGP with their cost and time impact on the projects. Using a machine-learning algorithm within the process of ranking and classifying the RFs will make the framework act as an automated decision-making tool, which could be used while planning for pipelines' maintenance in OGP projects. Based on the process of three hidden layers of machine learning algorithms, the main output of the framework is a prioritised/focused RFs, which will make the risk management plans more effective by focusing on the most influential of pipelines' failure causes.

This research's findings and recommendations are suitable and applicable for OGPs in Iraq and many other countries under similar situations. OGP stakeholders could use this research's findings to improve risk management during the pipeline projects' stages. Moreover, the findings of this paper could be applied to mitigate the risk in other critical infrastructures such as water supply network; transportation system (e.g., railway, highways, fuel supply, etc.); energy supply infrastructure (e.g., transmission and distribution lines, nuclear power generators, etc.); telecommunication and communication facilities. The RFs may be different in these projects, but insecure situations cause similar types of risks. Therefore, the methodology for identifying and evaluating the RFs and RMMs could also be similar.

Suggesting, recommending and/or identifying effective RMMs to manage the risk factors in the projects should be done based on an extensive review through the project stages. In other words, the perceptions of the manufacturers, the designers, the inspections and the operators should be collected and analysed in order to enhance the safety and security levels of the pipelines continually. This is because: (i) the impact of the risk factors changes as time passes, (ii) there are always new risk factors arising in the projects and (iii) the methods of risk management are continually improved. This means that the stakeholders and researchers should be prepared and updated about: (i) analysing and reanalysing the existing risk factors, (ii) revaluating the existing RMMs with regard to their effectiveness degree in the projects, (iii) analysing the newly arising risk factors, (iv) using new RMMs. Therefore, continuous extensive interviews and focus group studies with relevant experts in the projects should be conducted in order to recommend a robust system of risk management in the OGP projects.

6. Conclusions

A list of 30 RFs and 12 RMMs in the oil and gas pipeline projects have been identified based on a comprehensive review of the pipeline failure causes and risk management in the OGP projects worldwide. These findings help in overcoming the problems of the shortage of important data and intelligent information for the potential risk management processes in the OGP projects. In conclusion, there are only a few studies that have concurrently examined all potential pipeline RFs. There is the need for an accurate evaluation of the RFs, specifically regarding the issue of intentional TPD, because these factors have not been accurately evaluated in the past. The survey results, which are based on the fuzzy theory, have identified various risks, which are critical causes for the pipeline failures. The TPD is recognised as one of the most prevailing risks obstructing OGP systems and the development of new OGP projects. Attention needs to be paid to what motivates intentional TPD. The study provides some suggestions and recommendations for the risk mitigation methods in the OGPs which might help in reducing the impact of the RFs in the OGP projects. The findings and recommendations of this paper are relevant for the management of risks in the OGP particularly in Iraq and other countries having similar circumstances. However, the degree of impact of the RFs and the effectiveness levels of the RMMs might vary in different projects and locations with local risks. Hence, it is recommended that future study must involve distributing a wide range of questionnaires according to region/country in order to provide useful suggestions/recommendations for the effective risk management system in that region/country.

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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