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Using Stakeholders' Judgement and Fuzzy Logic Theory to analyze the Risk Influencing Factors in Oil and Gas Pipeline Projects: Case Study in Iraq, Stage II

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Abbreviations

Oil and Gas Pipelines	OGPs	Risk Index	RI
Risk Influencing Factors	RIFs	Fuzzy Inference System	FIS
Third-Party Disruption	TPD	Triangular Membership Functions	TrMF
Risk Mitigation Methods	RMMs	Trapezoidal Membership Functions	TlMF
Risk Analysis Framework	RAF	Computer –Based Risk Analysis Model	CBRAM

ABSTRACT

Oil and gas pipelines are safe and economic to petroleum products transportation. Nevertheless, enormous risk influencing factors are threatening the safety of these pipelines during the planning, construction and operations stages of these projects. Risk analysis in these projects is hindered by the inaccurate data about the probability and severity levels of the risk influencing factors. This problem is exacerbated further in troubled and developing countries, where the documentations and records are not at the best conditions. This study aims to identify and analyze potential risk influencing factors using a more integrated risk analysis framework. In this framework, the critical risk influencing factors and some of applied risk mitigation methods were identified based on a comprehensive review of pipelines projects worldwide. The impact of the identified factors and the effectiveness of mitigation methods were evaluated based on an industry-wide questionnaire survey in Iraq. A Computer-Based Risk Analysis Model (CBRAM) was designed to analyze the risk influencing factors using a fuzzy logic theory to consider any uncertainty that is associated with stakeholders' judgments and data scarcity. The CBRAM has confirmed the most critical risk influencing factors, which this study has explained the effective methods to manage them.

Keywords- Oil and Gas Pipelines; Risk Analysis; Risk Analysis Framework; Risk Mitigation Methods; Fuzzy Inference System; and Computer –Based Risk Analysis Model

1. Introduction

Oil and Gas Pipelines (OGPs) are economic and safe to transport the petroleum products. As Hopkins *et al*. [1] stated that the OGPs are 1.19 times cheaper than ships, 5.29 times cheaper than rail and trucks, 40 times cheaper than airplanes, 40 times safer than railroad tank cars and 100 times safer than tank trucks. Nevertheless, several Risk Influencing Factors (RIFs) may threaten the safety of these projects during the planning, construction, and operational stages including Third-Party Disruption (TPD), corrosion [2], design and construction defects, natural hazards, operational errors, and many others [3,4]. TPD refers to any external factors that can damage the pipelines [5], which is the major cause of OGP failure in European countries as well as in the USA [1]. Mitigating RIFs in OGP projects is valuable because it minimizes the massive losses that result from damage to the pipelines (e.g. life losses, disturbing the oil export activities, the cost of repairing the damaged pipes, the environmental consequences, and so forth). Moreover, it ensures the safety of the staff that work on OGP projects and the people who live in the surrounding areas. Therefore, the stakeholders in such projects must be aware of the RIFs that can damage OGPs. They must also have a robust risk mitigation system that can keep the RIFs at the lowest level, as far as possible.

As Fang & Marle [6] and Peng, et al [7] stated the management of the RIFs starts with identifying the RIFs, then analyzing them, responding to them, and, finally, control them. However, the existing Risk Analysis Frameworks (RAFs) have the following major and minor limitations regarding the identification and the analysis of the RIFs. The major limitation is that, it is worthwhile to analyze and rank the RIFs regarding their degree of influence on OGP projects considering their probability and severity levels [1] to identify the RIFs that require urgent attention. This is because dealing with each RIF as if it is the most critical one results in a large waste of resources [8]. However, the existing RAFs are not accurate enough to analyze the probability of all types of RIFs, especially TPD which is due to the absence of a historical database [7,9]. The minor limitation are: (1) the identification and registration of RIFs that may threaten the pipelines must be based on a real database and historical records of the pipelines' failure causes [10]. Hopkins *et al* [1] defined a real database as one that contains records of the pipelines' design; maps of their routes; pipeline fault and accident data; previous inspections and surveillance records; operational pressure and pressure test records; pipeline maintenance records; and modification records. However, the current RAFs have some limitations due to the inaccurate and uncertain information about the RIFs regarding their levels of probability and severity [11]. This problem is exacerbated further in troubled and developing countries where documentation is not in the best condition. (2) Most of the RAFs are mainly considering one or two RIFs at a time, which means they are not applicable to manage the safety of the pipelines' projects elsewhere [12]. (3) It is significant to evaluate the Risk Mitigation Methods (RMMs) in relation to their effectiveness in mitigating the RIFs. To make effective recommendations to mitigate the RIF in the projects. However, the effectives of the RMMs have not been evaluated in the previous studies about managing the RIFs in OGPs projects.

From the foregoing text, an authentic study about managing the RIFs in OGP projects is unachievable if the essential data about identifying the RIFs, analyzing them (e.g. their probability and severity of the RIFs), and evaluating the RMMs (e.g. a method's usability and effectiveness) are not accurate. These highlighted crucial problems hinder the efforts of risk mitigation in OGP projects in troubled and developing countries like Iraq. Hence, there is a vital need to help the stakeholders to focus on the most vulnerable segments of pipeline safety by employing a holistic risk analysis approach that can overcome the highlighted crucial problems.

Moreover, traditionally the RIFs are ranked based on their values of Risk Index (RI), which can be calculated using equation 1 [11, 13, 14].

$$Risk\ Index = Risk\ Probability \times Risk\ Severity \quad \ldots (1)$$

This method (i.e. equation 1) gives an opportunity to rank the RIFs using the RI, which reflect the both of the probability and severity levels of the factors. However, such a ranking method might not accurately reflect criticality of the RIFs in OGP projects in Iraq for the following two reasons. Firstly and majorly, this equations requires accurate values about the probability and severity levels of the RIFs, which are difficult to obtain in the case study area "Iraq" because of the limitations that have been explained earlier in the paper, see the second paragraph in section 1. Therefore, there is a need to analyze the RIFs deepening on their range of probability and severity levels rather than accurate values about their probability and severity levels. Secondly, because an RIF with a high severity level could still be considered as a critical RIF that needs an urgent attention of management. However, the same RIF could not come at the top of the ranking if it had a low probability level. This is similar if the probability level of the RIF is high and the severity level is low, which is one of the RI method's limitations.

Additionally, Iraq after 2003 experienced a high demand for new OGP projects in addition to rehabilitating the existing pipelines to meet the requirements of the rapid increase in oil exports. However, the inadequacy of managing several RIFs that threatened these projects had a negative effect on the country's oil export activities. For example, there was no available or accessible data that could be used to accurately identify the RIFs that may affect the OGPs in Iraq.

The aim of this paper, therefore, is to develop an integrated RAF that follows qualitative data analysis approach to identify the RIFs and RMMs associated with OGPs; and statistical methodology-based and fuzzy logic theory approaches to analyze the RIFs and RMMs in a more accurate way to enhance the safety of OGP projects, particularly in trouble countries.

To overcome the problem of a scarcity of data and a lack of information about the causes of pipeline failure and risk mitigation methods, a worldwide, qualitative document analyses was carried out to provide a review about OGPs RFs and risk mitigation methods, specifically in insecure environments. Nandi et al., [15] found that there are many of risk factors are effecting the safety 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 conditions. Moreover, Rowland, [16] say the exposed pipelines and threats to staff are effacing the safety of OGPs in Nigeria. Srivastava & Gupta [8] draw a scenario about a terrorism attack that might happened in India and they expect risk factors like insecure areas, easy access to pipeline and hacker attacks on the operating or control systems might effect OGPs in their country. Other studies added more risk factors like lawlessness, low public legal and moral awareness, and vehicular accidents [7], improper safety regulations; design, construction and material defects and geological risks [17] conflicts over land ownership [18], leakage of sensitive information [19], and animal accidents [20].

Moreover, the existing RAFs are limited to analyzing only one type or two types of RIFs at once. For instance, European countries mainly focus on corrosion and stress-strain risks because their pipelines are underground and they are less subject to sabotage risk. USA focuses more on the terrorism risk, especially after 9/11, in addition to corrosion because the USA uses underground pipelines as well. African countries direct more attention toward thefts risks because the stolen products might be sold on the illegal market. In the meantime, due to current globally insecure environments, critical infrastructures like OGPs are potential targets for saboteurs. Correspondingly, intentional TPD like (terrorism, sabotage and theft) has been recognized as one of the most dominant mechanisms of OGP failure globally [2,4].

Several studies were analyzed to develop the RAF. In Pakistan, Mubin and Mubin [20] developed a risk management model to provide recommendations to manage the RIFs in gas pipeline projects during the construction stage. In this model, a data bank was created to register the RIFs, which were simulated using Monte Carlo simulation. Schwarz *et al.* [16] developed a risk management procedure to evaluate the RIFs to support decision-making processes in construction projects. The model started by defining the scope of the projects, the criteria of the risk management, and identifying the RIFs. Then, experts' judgments and artificial neural network were applied to analyze the RIFs. These two models identified the RIFs based on analyzing documents relating to local projects. El-Abbasy *et al.* [17] developed a framework to predict the conditions of offshore OGPs in Qatar. In this study, they employed historical data and artificial neural network to priorities the maintenance work for these pipelines. To assess the performance of water distribution pipeline network in Qatar and Canada, El-Abbasy *et al*. [18] carried out similar work using fuzzy analytical network. However, none of the reviewed models have identified and evaluated RMMs.

Moving forward in this paper, section 2 provides a detailed review related to identifying and classifying the pipeline RIFs and RMMs. The methodology of designing the RAF and analyzing the RIFs and RMMs is explained in section 3. Section 4 shows the results of the study and section 5 discusses them. Section 6 highlights the conclusion of the study and the recommendations for future work.

2. Research Methodology

The development of an integrated RAF is a part of the methodology of this paper to mitigate the RIFs. Accordingly, this paper adopts these models to develop a more holistic and effective RAF via bridging the highlighted gaps in these models as shown in Figure 1.

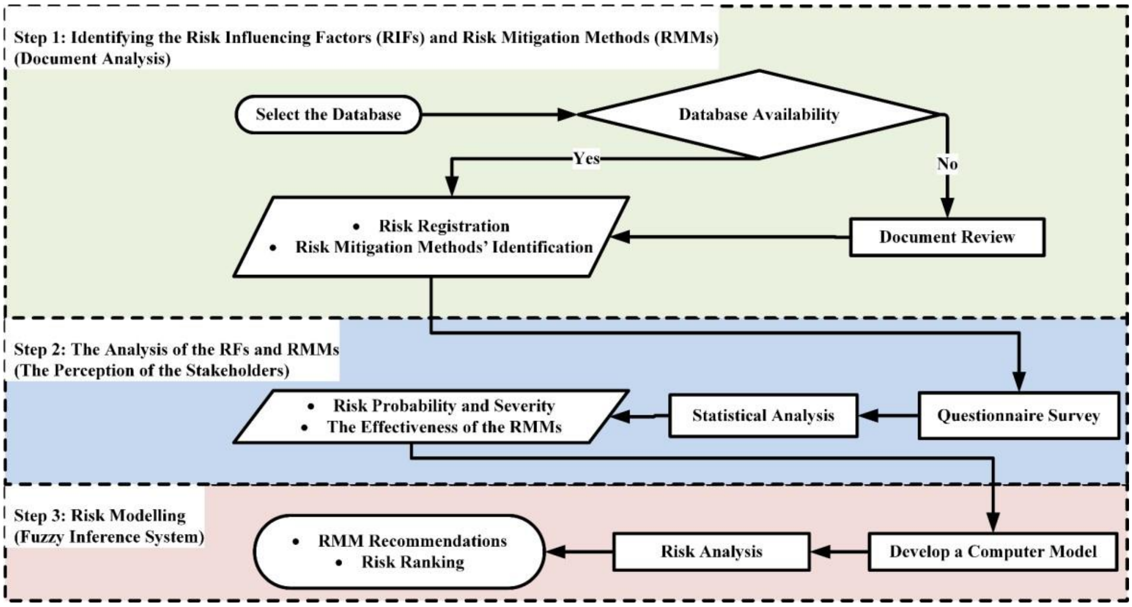

Figure 1: An Integrated Risk Analysis Framework (RAF).

Following the process of the developed RAF, step 1 was about identifying the associated RIFs and RMMs based on the available database(s) and the previous literature. Deterministic approach and simulation are the main two ways used to calculate the probability of failure. The deterministic approach utilizes the related data to assess the probability conditions of RIFs. And the simulation approaches utilizes correlation analysis with the age and the conditions of the pipes to assess the probability of failure based on the historical records [19]. Risky environments, similar to those in Iraq, require further investigations to understand the RIFs and RMMs. These investigations prompted the need for step 2, which was about designing a questionnaire survey to collect the stakeholders' opinions about the levels of the "probability and severity" of the RIFs and the "usability and effectiveness" levels of RMMs as they have real experience of OGP issues.

The uncertainty and the lack of such historical data are the main challenges for managing infrastructure projects and collecting supplementary data. Meanwhile, knowledge, and analytical or simulation techniques are the most effective way to deal with the uncertainty [25]. So, step 3 was about using the findings of steps 1 and 2 as inputs for a Computer-Based Risk Analysis Model (CBRAM) that was developed to model the RIFs and RMMs using Mamdani algorithm and If-Then rules within the Fuzzy Inference System (FIS) toolbox of MATLAB.

2.1. Step 1: Identifying the Risk Influencing Factors (RIFs) and Risk Mitigation Methods (RMMs).

Extensive investigations were carried out to identify these RIFs in OGP projects within different circumstances, firstly worldwide and secondly in countries where OGPs suffered similar security problems to those in Iraq. Based on [5,26,27,28], which are the stage I of this ongoing research, 30 RIFs and 12 RMMs were identified, as listed in **Error! Reference source not found.** and Table 2 respectively.

Despite these investigations containing comprehensive and worthwhile information about the RIFs based on extensive literature, there was still a lack of data and certainty about the hazardous events (e.g. risk probability and severity), especially in areas where there are few historical records. Practically, the field of OGP projects is the main source of such data rather than the theoretical document analysis.

2.2. Step 2: Questionnaire Design and Data Sampling

The survey targeted stakeholders from OGP projects in Iraq, like designers, planners, consultants; construction, operators, and maintenance workers; owners, clients, and researchers to collect their perceptions about the RIFs and RMMs in their projects. Before distributing the survey, a pilot survey was carried out to improve the clarity of the questions and test the functionality of the survey [28]. The snowball sampling technique for data collection was applied to collect enough respondents to the survey [30]. The survey was distributed using an online webpage. The respondents were assured that their participations will be analyzed confidentially and anonymously.

In the survey, a 1 to 5 index range was used to transform the probability and severity of the RIFs into a unified point rating system [19]. The probability levels of the RIFs were evaluated on a scale [almost certain, likely, possible, unlikely, and rare]. The severity levels of the RIFs were evaluated on a scale [catastrophic, major, moderate, minor, and negligible]. The usability of the RMMs was evaluated on a scale of [almost certain used, likely used, possible used, unlikely used, and rare used]. The effectiveness of the RMMs was evaluated on a scale of [extremely effective, very effective, moderately effective, slightly effective, and insignificant]. As well as, there were two open-ended questions to add more RIFs and RMMs to the working list. The results of analyzing the RIFS and RMMs based on the survey are shown in Table 1 and Table 2, respectively. Table 3and Table 4 are showing the participants' demographic information and the reliability level of the survey, respectively.

Table 1: The results of analyzing the based on the survey

RIFs (from the literature) [5,26,27,28,29]	**Probability**	**Severity**	**RI (using Eq. (1))***	**Rank**
Terrorism & sabotage	3.995	4.490	3.59	1
Corruption	3.980	4.323	3.44	2
Low public legal & moral awareness	3.712	4.106	3.02	4
Insecure areas	3.717	4.192	3.05	3
Thieves	3.692	4.081	3.01	5
Corrosion & lack of protection against it	3.687	3.990	2.94	6
Lack of proper training	3.646	3.859	2.80	11
Improper safety regulations	3.687	3.960	2.91	7
Exposed pipelines	3.667	3.949	2.87	8
Improper inspection & maintenance	3.657	3.899	2.83	10
Conflicts over land ownership	3.495	3.646	2.57	19
Shortage of the IT services & modern equipment	3.667	3.924	2.86	9
Weak ability to identify & monitor the threats	3.631	3.848	2.75	12
Design, construction & material defects	3.333	3.611	2.48	21
Lack of historical records about accidents and risk registration	3.566	3.662	2.64	17
The pipeline is easy to access	3.631	3.773	2.70	13
Limited warning signs	3.626	3.732	2.68	14
Little research on this topic	3.621	3.697	2.66	15
Lawlessness	3.606	3.682	2.65	16
Stakeholders are not paying proper attention	3.530	3.652	2.59	18
Public's poverty & education level	3.449	3.611	2.52	20
Inadequate risk management methods	3.227	3.505	2.24	23
Leakage of sensitive information	2.980	3.399	2.09	25
Threats to staff (kidnap and/or murder)	3.323	3.571	2.35	22
Operational errors e.g. human error and equipment failure	3.101	3.409	2.19	24
Geological risks like soil movement and landslides	2.747	3.182	1.75	26
Natural disasters & weather conditions	2.652	3.066	1.63	27
Hacker attacks on the operating or control system	3.066	3.066	1.33	29
Vehicle accidents	2.465	2.970	1.34	28
Animal accidents	1.894	2.020	0.77	30
*For example: $RI\ for\ Terrorism\ \&\ sabotage = (3.995 \times 4.490)/5 = 3.587$.				

The identified RMMs and results of evaluating their levels of usability and effectiveness are presented in Table 2.

Table 2: The results of the usability and effectiveness of the RMMs.

RMMs (from the literature) [5,26,27,28,29]	Usability	Effectiveness
Anti-corrosion such as isolation & cathodic protection	3.652	4.23
Move to an underground pipeline	3.475	4.07

Advanced technological & professional remote monitoring	3.616	4.0
Proper inspection, tests & maintenance	3.768	3.83
Proper training	4.051	3.79
Avoid insecure areas	4.247	3.78
Anti-terrorism design	3.783	3.78
Avoid registered risks & threats	3.727	3.77
Protective barriers & perimeter fencing	3.606	3.69
Government/public cooperation	3.480	3.57
Warning signs & marker tape above the pipeline	3.278	3.55
Foot & vehicle patrols	3.677	3.53

A wide range of stakeholders was represented in this survey with a total of 198 respondents, as shown in Table 3. Correct sampling and representing all of the stakeholders' categories enhances the results of RIFs analysis and RMMs evaluation. Because the whole categories of stakeholders were represented in the survey.

Table 3: Participants' demographic information (F is the Frequency).

Occupation	F
Consultant, planner or designer	14
Member of a construction team	71
Operator	41
Owner or client	39
Researcher or student	33

Experience (year)	F
Less than 5	74
5 to 10	67
10 to 15	29
More than 15	28

Education	F
Vocational	3
High school	28
Bachelor's degree	106
Master's or PhD	61

The Cronbach's alpha correlation coefficient (α) was calculated to measure the reliability level of the survey [36,37]. 0.7 indicates a minimum level of reliability [38], which means the reliability level of the questions individually and the whole survey is acceptable as shown in Table 4.

Table 4: The case processing summary of (α) (from SPSS).

Case Processing Summary	Valid	Valid %	α
The whole questionnaire	198	100	0.910
The probability question	198	100	0.919
The severity question	198	100	0.863
The usability question	198	100	0.867
The effectiveness question	198	100	0.792

2.3. Step 3: Computer –Bassed Risk Analysis Model (CBRAM)

The mean of the five-point scale was calculated to find the values of probability and severity of the RIFs. The RI values were calculated for each RIF using equation 1. Table 3 demonstrates analysis results of RIFs.

As Dai and Li [31] and Yazdani-Chamzini and Zavadskas [32] concluded, uncertainty could arise during risk analysis due to data scarcity or incomplete information about the RIFs and experts' judgments about their probability and severity. In the meantime, the use of an appropriate risk evaluation tool can support the decision-maker with regard to the safe design and operation of an OGP [13, 31,33]. In such a situation, the fuzzy logic theory is a useful tool that can be employed to handle risk analysis for many scenarios when there are no precise values and sharp boundaries [34]. In comparison with the RI method as shown in equation 1, the fuzzy approach is more adaptable in the case when there are no accurate values about the probability and severity levels of the RIFs, as it uses fuzzy expressions and linguistic labels instead of rigid mathematical rules and equations to analyze them [9]. We have designed a CBRAM using MATLAB to analyze each one of the RIFs. The results of the survey (which are probability and severity) were used as inputs for this model. In accordance with the conventional fuzzy systems, the process of analyzing RIFs is achieved over three stages namely, fuzzification, knowledge base, and defuzzification, as shown in

Figure 2 [13,31,33].

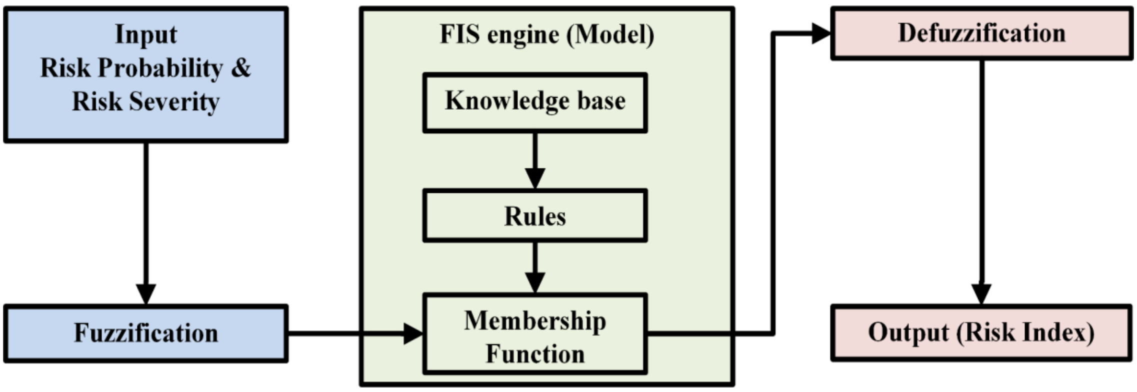

Figure 2: The process flow diagram of Fuzzy Interface System (FIS).

Fuzzification is about providing crisp inputs for the FIS by generating sets of membership functions. To generate such crisp inputs, the Min-Max membership function was used in this study as explained in Figure 3. Two types of membership functions proposed by the Mamdani mathematical algorithm were applied in this paper: Triangular Membership Functions (TrMF) (see Figure 4) and Trapezoidal Membership Functions (TlMF) (see Figure 5). The difference between the two membership functions is that the TrMF where full compliance is only attained at the maximum score of RI; where the TlMF membership function has an upper and a lower limit. Which means that the RI score is considered fully compliant once it hits the upper limit.

The Knowledge base is about defining the conditional statements "If-Then rules" to control the behavior of the FIS. For example, rule number 1 says, if the probability is VL and the severity is VL then the RI is VL. Rule number 6 says, if the probability is L and the severity is VL then the RI is L. Rule number 8 says, if the probability is L and the severity is M then the RI is M. Rule number 9 says, if the probability is L and the severity is H then the RI is M. Rule number 14 says, if the probability is M and the severity is VH then the RI is H. Rule number 22 says, if the probability is VH and the severity is VL then the RI is M. Finally, the centroid method of defuzzification was used to obtain the final outputs (crisp RI) (see Figure 3).

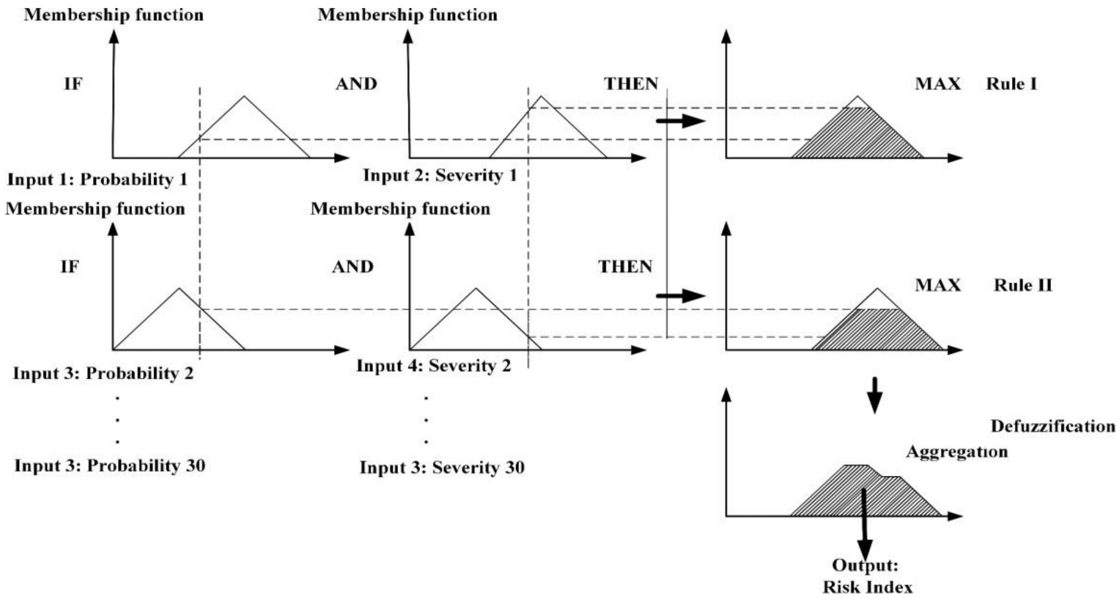

Figure 3: FIS with two inputs (Risk Probability and Risk Severity) and one output (Risk Index) [35].

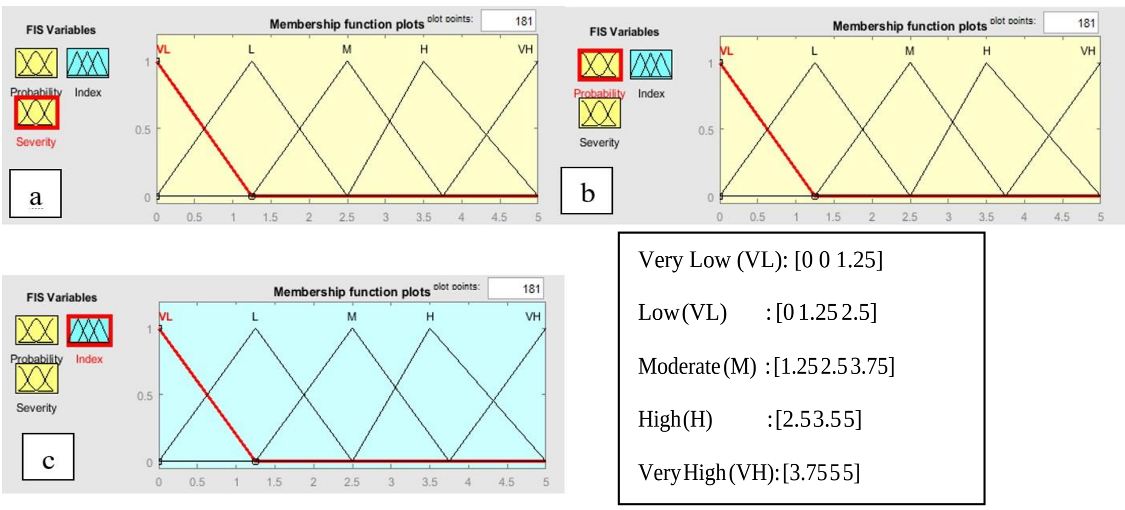

Figure 4: Fuzzy triangular membership functions for (a) Risk Probability, (b) Risk Severity, and (c) Risk Index.

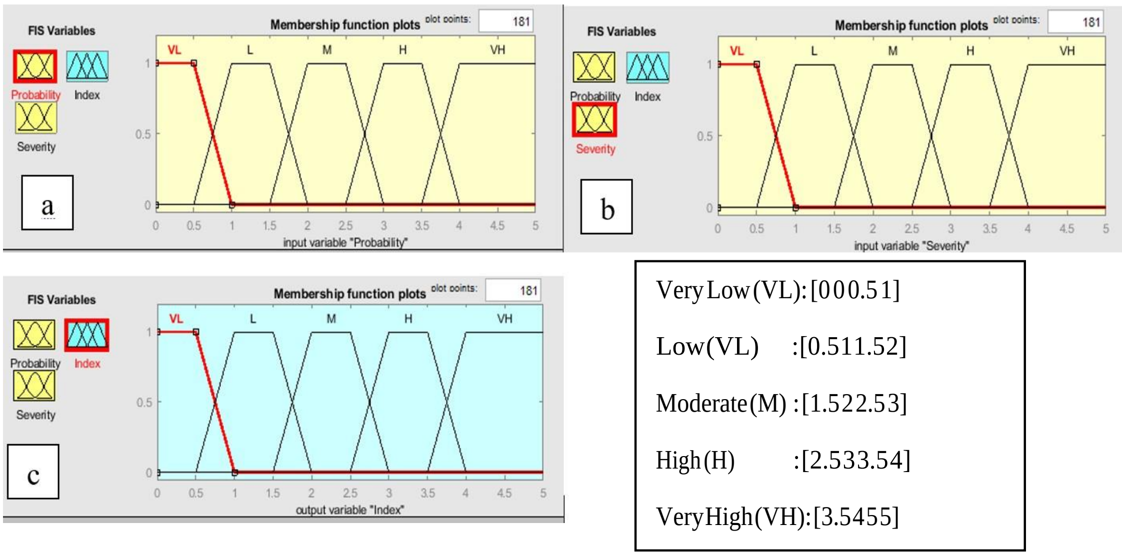

Figure 5: Fuzzy trapezoidal membership functions for ((a) Risk Probability, (b) Risk Severity, and (c) Risk Index. FIS provides powerful rule viewer tools (as shown in Figure 6).

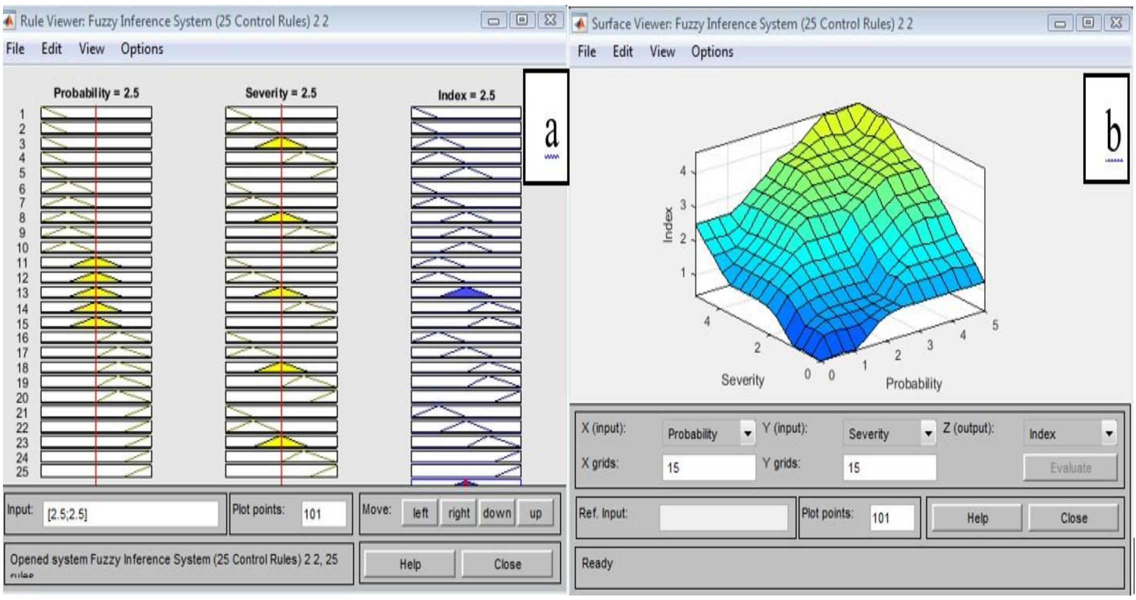

Figure 6: (a) Rule viewer, and (b) 3D risk in FIS.

3. Results

Table 5 presents the results of CBRAM that was developed using the FIS toolbox in MATLAB. The two types of membership functions gave different values of RI without affecting the ranking of these RIFs.

Table 5: The ranking of RIFs using FIS

RIFs	RI (TrMF)	Rank	Rage	RI (TlMF)	Rank	Rage
Terrorism & sabotage	3.99	1	**H**	4.38	1	**VH**
Corruption	3.87	2	**H**	4.38	2	**VH**
Low public legal & moral awareness	3.80	3	**H**	4.36	3	**VH**
Insecure areas	3.76	4	**H**	4.34	4	**VH**
Thieves	3.75	5	**H**	4.33	5	**VH**
Corrosion & lack of protection against it	3.72	6	**H**	4.31	6	**VH**

Lack of proper training	3.71	7	**H**	4.29	7	**VH**
Improper safety regulations	3.70	8	**H**	4.20	8	**VH**
Exposed pipelines	3.70	9	**H**	4.15	9	**VH**
Improper inspection & maintenance	3.69	10	**H**	4.13	10	**VH**
Conflicts over land ownership	3.68	11	**H**	4.04	11	**VH**
Shortage of the IT services & modern equipment	3.68	12	**H**	4.01	12	**VH**
Weak ability to identify & monitor the threats	3.67	13	H	3.87	13	H
Design, construction & material defects	3.64	14	H	3.78	14	H
Lack of historical records about accidents and risk registration	3.60	15	H	3.72	15	H
The pipeline is easy to access	3.57	16	H	3.67	16	H
Limited warning signs	3.56	17	H	3.65	17	H
Little research on this topic	3.55	18	H	3.63	18	H
Lawlessness	3.54	19	H	3.61	19	H
Stakeholders are not paying proper attention	3.51	20	H	3.54	20	H
Public’s poverty & education level	3.49	21	H	3.52	21	H
Inadequate risk management methods	3.48	22	H	3.52	22	H
Leakage of sensitive information	3.38	23	H	3.28	23	H
Threats to staff (kidnap and/or murder)	3.35	24	H	3.25	24	H
Operational errors e.g. human error and equipment failure	3.30	25	H	3.25	25	H
Geological risks like soil movement and landslides	3.17	26	H	3.25	26	H
Natural disasters & weather conditions	3.10	27	H	3.25	27	H
Hacker attacks on the operating or control system	3.03	28	H	3.18	28	H
Vehicle accidents	2.80	29	M	2.68	29	M
Animal accidents	1.95	30	L	2.50	30	M

4. Discussion and Limitations

OGPs are a safe mode by which to transport petroleum products as long as the stakeholders are following the design codes; inspecting and maintaining the pipes properly during service; and adopting an adequate risk management system to mitigate the RIFs. The existing RAFs cannot effectively manage the RIFs in OGP projects in troubles countries due to the fact that these methods cannot accurately calculate the probability of the RIFs, especially TPD risks because there is no real data available about such risk yet. The lack of information about the RIFs and RMMs and the inaccuracy of the assessment of the RIFs will result in an uncertain evaluation of OGP risks. In other words, the uncertainty is one of the major problems in risk assessment, and makes risk analysis a more complicated task. Therefore, there is an urgent need for an accurate evaluation of OGP RIFs, particularly the problem of TPD, because these factors have not been accurately evaluated. Therefore, the applied RAFs in the other countries 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 risks.

The literature review findings were a list of RIFs and a list of RMMs associated with OGP projects in different countries across the world, such findings could help to overcome the problem of data scarcity about RIFs. By collecting the required information about the RIFs and RMMs from various trusted sources like the stakeholders, the completed surveys will provide real information to guide future actions relating to OGP risk management. However, this method depends on the stakeholders’ acceptance and willingness to cooperate with the authors, which is one of its main advantages. The method of collecting stakeholders' perceptions could reduce the time and cost of investigations; increase their awareness and provide the opportunity to educate them; and provide an opportunity to meet those who are responsible for risk management.

Both the probability and severity level of the RIFs were calculated based on a questionnaire survey. To overcome the uncertainty about ranking the RIFs, they have been assessed by using a CBRAM that was conducted using fuzzy logic theory. The ranking of the RIFs based on the results of the survey shows that sabotage, official corruption, lawlessness, insecure areas, and thieves are the most critical RIFs. In contrast, it was found that the RIFs with the lowest impact on the projects are geological RIFs, natural disasters and weather conditions, hacker attacks on the systems, and vehicles and animals accidents. Ranking the RIFs based on the results of FIS shows that there was no change for the 1st, 2nd, 5th, 6th, 10th, 26th, 27th and 30th RIFs. FIS classified the RIFs by sets of ranges: very low, low, moderate, high, and very high (see Figure 4 and Figure 5), which helps to rank the RIFs by their ranges of risk rather than uncertain values of RI. The bold text in **Error! Reference source not found.** shows the difference between risk ranges for these two membership functions. FIS provides a powerful surface viewer tool which presents the ranking of the RIFs in a 3D risk matrix rather than in tabular view, which helps to view the RIFs by their zones of influence on certain pipeline projects, as shown in Figure 6.

The survey has highlighted some of the RFs that might be unique in OGP projects in Iraq, as they have not been mentioned in the past studies. For example, pumping more than one type of petroleum product and pumping crude oil from different fields in the same pipe, and the salts and metals contents in the transported products, which cause internal corrosion for the pipes. In addition to the other RFs like, not taking the future urban planning into account, which might cause conflate about the land ownership in the future. The external oil spots that negatively affect the pipes, which cause external corrosion for the pipes and maintenance difficulties. Poor quality of the pipes and the using the pipes that older than the design age.

Based on the survey results, anti-corrosion measures such as isolation and cathodic protection were rated as effective RMMs. Corrosion could be protected by providing the pipelines with an external coating, using isolation layers, a cathodic protected 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 [1]. The main disadvantage of this method is the added cost to the projects and it might slowdown 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 unauthorized activities in OGP project zones like terrorism, sabotage, thievery, illegal excavation, and construction activities near to the pipeline. Using these methods carry some 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, 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 like (landslides, foundation collapse, illegal building, blast construction, live ground loads, earthquakes, floods, operational errors, control system failures, road construction, farming and drilling, etc) during inspection periods.

Proper operational practices, inspections, and maintenance reduce operative RIFs and mechanical failure for the pipeline. Most operators in OGP projects control operational RIFs by limiting the operational stress (operating pressure), and following the regulations and codes. However, Hopkins *et al.* [1] 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 produce might potentially miss new RIFs if RIF identification and registration are not up to date; and (iii) this procedure creates an inflexible practice of risk analysis that restricts the stakeholders in applying new methods of identifying and mitigating the RIFs.

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 like emergency contact (emails and phone numbers) and phone lines; mailboxes, and so forth) could help people to report any threat to a pipeline.

Some of the RMMs have been added to this paper after analyzing the percipients' comments on the survey. The RMMs are (1) expand the protection zones along with the pipelines and remove the random buildings and unauthorized actives nearby the pipeline. (2) Use the rivers and lakes to extend the pipelines in the insecure areas despite the construction cost and the risk of corrosion. (3) Pump only one type of product in the pipeline and use a different pipeline for each oil field. (4) Use optimizers and remove the salts and metals before pumping the petroleum products.

Finally, the developed RAF cannot link the RIFs or draw scenarios of failures to calculate the consequences of any hazardous event. In addition, it does not provide a decision support tool that has an automated system to analyze the information (e.g. RIFs, Risk Probability, Risk Severity, RMMs and the effectiveness of RMMs).

5. Conclusion and Future Work

Risk management cannot protect pipelines from all RIFs. Meanwhile, it should recognize the best way to mitigate the RIFs. The developed RAF provides a comprehensive and systematic approach to OGP risk management, specifically for organizations that have just begun to mitigate OGP RIFs more effectively.

The results of the questionnaire survey were used to provide real input for a CBRAM to analyze the RIFs and RMMs by using the FIS toolbox in MATLAB. Using fuzzy logic in the process of the risk assessment remedies the problems of the traditional approaches to risk management.

Iraq needs to overcome many formidable challenges and RIFs that are obstructing the OGP system and the development of new projects. While various problems and risks were found to be causes of pipeline failure, TPD is recognized as one of the most prevalent causes of OGP failure in Iraq. Assessing the RIFs using FIS shows the range of the risk is from low to high (by using TrMF), and from moderate to very high (by using TlMF), and no risk was ranked as very low in either of these two functions. The CBRAM shows that terrorism, official corruption, insecure areas, and lawlessness are the most critical

RIFs. The range of the RIFs reflects the fact that the critical RIFs in OGPs in Iraq are the safety and security RIFs, which could threaten these projects during their planning and design, construction, and operation stages. This means managing the RIFs in OGP projects is not limited to one project stage. Therefore, different risk mitigation methods were suggested to mitigate the RIFs. Also the survey results showed that explicit attention needs to be paid to find out exactly what motivates intentional TPD. At the same time, the results revealed that the anti-corrosion efforts are the most effective RMMs, and the stakeholders who participated in this research stated that the underground OGPs are safer than the aboveground ones in relation to their susceptibility to the RIFs. This means the stakeholders assumed that the construction and geological RIFs that result from moving the pipelines underground have less influence compared to the TPD that results from having exposed pipelines.

In this paper, a new database has been generated to store real information about RIF identification, risk analysis, and RMM evaluation to be used for risk management actions and by future researchers. The findings and recommendations of this paper are suitable for and applicable to manage OGP RIFs in Iraq and many other countries with similar situations.

The Stage III of this study (the future work) is to analyze the comments of the participants (from the open-ended questions in the survey) to add more RIFs and RMMs to the working list. Additionally we will compare the influence of the RIFs using Analytic Hierarchy Process (AHP) to provide more verified ranking of the RIFs. Also, to estimate the consequence the hazardous events we will use a neural network analysis tool to draw some pipe failure scenarios. Analyzing the cost-effects that result from applying the RMMs in OGP projects will be done by conducting some interviews with experts in these projects. As well as, one of the decision support tool that can analyze the inputs (e.g. RIFs, Risk Probability, Risk Severity, RMMs, the effectiveness of RMMs and the cost) will be developed to help the stakeholders during the decision-making process tool to choose safe routes for the pipelines and the effective RMMs. Moreover, we would like to pay attention to the fact that fuzzy logic based expert system applies an imprecise terms that could lead to poor performance in many situations, where identifying risk level of OGPs stations includes many overlapping variables changing over time. This assesses risk level in such big projects not really and can affect decision-making as well as the validity and reliability of decisions made by such systems. Consequently, we aim to take a step forward and consider sophisticated intelligent approaches to identify risk levels of such big project. In our upcoming study that will be available online soon, we are applying set of machine-learning methods for the same purpose. The final results of this ongoing research will be conducted with some interviews with experts to analyze the cost-effects that result from applying the RMMs in OGP projects. This research will be applied on real case study at the final stage of it. Over and above, choosing the pipelines' routes accurately during the planning and design stage avoid to the insecure, high population, traffic, natural disasters, and animals areas could minimize the RFs that results from such areas. Therefore, design a route analyses to choose safe routes for the new pipelines projects is a part of the future work of this study, Such a tool will be considers in another publication, which will deliver stage IV of the study.

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