Development of Risk Optimisation Model for Oil and Gas Transportation Pipeline Routes

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Abstract. Identifying safe routes for the pipelines that transport Oil and Gas (O&G) products is a challenging topic in the current environment; particularly in the insure countries. Because the relevant data about the probability and severity levels of the Risk Factors (RFs) that affect the safety of these pipelines are rare. Which makes the existing risk assessment tools ineffective to analyse these RFs and identify safe route for these pipelines. Hence, this paper aims to develop a risk assessment tool that can identify safe routes for the new O&G pipelines in Iraq in a systematic way using the following steps. Firstly, an industry-wide questionnaire survey was conducted to gather the data about the probability and severity levels of the RFs in such projects in Iraq. Secondly, the Fuzzy Inference System (FIS) in MATLAB was used to analyse and rank the RFs. Because the FIS can reduce the uncertainty in risk analysis, which results from the lack of data and the biasness of stakeholder’s judgments about the RFs. Thirdly, the existing information from the new pipelines projects were analysed to identify the potential RFs in the proposed routes for these projects. As the O&G pipeline network in Iraq is above-the-ground, this paper focused on the RFs that affect this type of pipelines. Fourthly, the safest route for the new pipeline was identified by optimising the risk index value for each route. While, the route that has less value of risk index is the safest route. This paper analysed the five routes that were suggested to build a new gas export pipeline in Waist in Iraq. It was found that route number 4 is the safest route for this pipeline.

1. Introduction
Oil and Gas Pipelines (OGPs) must be planned, designed, installed, operated and maintained regarding the safety requirements to transport the petroleum products safely. However, several Risks Factors (RFs) are threatening the safety of these projects, such as terrorism, sabotage, thefts, corrosion, design and construction defects, natural hazards, operational errors and many more. Meanwhile, the current risk assessment tools are inaccurate to analyse the RFs in OGP projects in the developing countries due to the data scarcity and lack of research about them in these countries. As stated by Kraidi et al., [1], the risk management system in OGP projects in Iraq suffers from the scarcity of data about the probability and severity levels of the RFs in these projects. The alternative way of identifying and analysing the RFs in such a situation is via conducting a literature review about the RFs in OGP projects and collecting the stakeholders’ perceptions about them [2]. Nevertheless, analysing the RFs based on the stakeholders’ perceptions results in uncertain results. Because the stakeholders have different
perceptions about the probability and severity levels of the RFs [3]. Therefore, the RFs in this paper will be analysed using the Fuzzy Inference System (FIS) in MATLAB. Because the FIS uses linguistics terms (e.g. very low, low, moderate, high and very high) to analyse the RFs, which is useful to calculate the Risk Index (RI) of the factors when there are neither sharp boundaries nor precise values of their probability and severity levels [4].

2. Aims and objectives
The purpose of the paper, therefore, is to develop a risk assessment tool that helps in analysing the RFs in the pipelines’ projects and choosing safe routes for the new projects in a systematic way. This tool will analyse the OGP projects in two cities southern of Iraq, which are Waist (Al Kut) and Basra. Because the current risk management system in these projects is inadequate, which obstructs gas export activities. Figure 1 shows the flowchart of the risk assessment tool.

3. Research approach
Figure 1 explains the flowchart of the risk assessment tool.

Following figure 1, the risk assessment tool works in two stages. In stage I, extensive investigations were carried out to identify the RFs in OGP projects in different countries and circumstances to overcome the problem of data scarcity about them in Iraq. The identified RFs were classified into five groups based on their type. Then, the RFs were evaluated via a questionnaire survey that was distributed amongst the stakeholders in OGP projects in Iraq using an online survey tool. The outputs of the survey were the weight of each group of the RFs (A). As well as the probability and severity levels of the RFs, which were used as inputs for the FIS in MATLAB to calculate the RI of the RFs, see Figure 2. Appendix A shows examples of the questionnaire survey. Appendix A shows the size of the sample and the response rat. B is the weight of the RF that considers the weight of its groups (A) and its value of RI. The results of (Stage I) of risk analysis are shown in Error! Reference source not found..

\[
B = A \times RI
\]  

(1)

\[
C = \left(\frac{B}{\text{Sum B}}\right) \times 100\%
\]  

(2)

\[C\] is the weight of the RFs from 100%.
Stage II of the risk assessment tool is about analysing the RFs in specific routes of OGPs. This paper has analysed the five proposed routes for a new gas pipeline, which will be built from Badra gas field in Waist to Basra in order to export the extracted gas from that field via the sea. The available documents about these five routes were subjectively analysed to identify the RFs that might threaten the pipelines in these routes. $D$ is the weight of the RFs in the route. Based on the document analysis, in the case that the RF is threatening the pipeline, then $D = 1$; otherwise, $D = 2$. $E$ is the final weight of the RFs in the route.

$$E = C \times D$$

(3)

Where $C$ is the weight of the RFs in OGP projects in Iraq overall and $D$ is the weight of the RFs within the specific route. $F$ is the total risk index in the route.

$$F = SUM(C)$$

(4)

The route that has less value of $F$ is the safest route. Because it has the less total impact of the RFs. The results of analysing the OGPs’ routes are shown in Table 2.
Table 1. The identified RFs from the literature review and their values of probability, severity and index.

| RFs [1-3 and 5,6] | Type* | A  | Probability | Severity | RI  | B  | C  |
|-------------------|-------|----|-------------|----------|-----|----|----|
| Terrorism, sabotage and the security risk | S&S   | 2.84 | 3.995       | 4.490    | 3.99 | 11.33 | 5.43 |
| Stealing the products | S&S   | 3.692 | 4.081       | 3.75     | 10.65 | 5.10 |
| Public awareness | S&S   | 3.712 | 4.106       | 3.80     | 10.79 | 5.17 |
| Staff threats | S&S   | 3.323 | 3.571       | 3.35     | 9.51  | 4.55 |
| Socio-political effects | S&S | 3.449 | 3.611       | 3.49     | 9.91  | 4.75 |
| Leakage of sensitive information | S&S   | 2.980 | 3.399       | 3.38     | 9.60  | 4.60 |
| Corruption | R&L   | 3.980 | 4.323       | 3.87     | 5.61  | 2.69 |
| The absence of the law on TPD | R&L | 3.606 | 3.682       | 3.54     | 5.13  | 2.46 |
| Lack of risk management practice | R&L | 3.530 | 3.652       | 3.51     | 5.09  | 2.44 |
| Lack of proper training | R&L | 3.646 | 3.859       | 3.71     | 5.38  | 2.58 |
| Lack of risk registration | R&L | 3.566 | 3.662       | 3.60     | 5.22  | 2.50 |
| Little research on this topic | R&L | 3.621 | 3.697       | 3.55     | 5.15  | 2.46 |
| The geographical location | PL | 3.717 | 4.192       | 3.76     | 8.91  | 4.27 |
| The pipeline is easy to access | PL | 3.631 | 3.773       | 3.57     | 8.46  | 4.05 |
| Land ownership conflicts | PL | 3.495 | 3.646       | 3.68     | 8.72  | 4.18 |
| Geological risks | PL | 2.747 | 3.182       | 3.17     | 7.51  | 3.60 |
| Vehicles accidents | PL | 2.465 | 2.970       | 2.80     | 6.64  | 3.18 |
| Animals accidents | PL | 1.894 | 2.020       | 1.95     | 4.62  | 2.21 |
| Improper safety regulations | HSE | 3.687 | 3.960       | 3.70     | 6.99  | 3.35 |
| Improper inspection and maintenance | HSE | 3.657 | 3.899       | 3.69     | 6.97  | 3.34 |
| The risk related to the aboveground pipeline | HSE | 3.667 | 3.949       | 3.70     | 6.99  | 3.35 |
| Limited warning signs | HSE | 3.626 | 3.732       | 3.56     | 6.73  | 3.22 |
| Inadequate risk management | HSE | 3.227 | 3.505       | 3.48     | 6.58  | 3.15 |
| Natural disasters | HSE | 2.652 | 3.066       | 3.10     | 5.86  | 2.81 |
| Corrosion | OC | 3.687 | 3.990       | 3.72     | 5.39  | 2.58 |
| The weak ability to manage the risk | OC | 3.631 | 3.848       | 3.67     | 5.32  | 2.55 |
| Shortage of modern equipment | OC | 3.667 | 3.924       | 3.68     | 5.34  | 2.55 |
| Design, construction and material defects | OC | 3.333 | 3.611       | 3.64     | 5.28  | 2.53 |
| Operational errors | OC | 3.101 | 3.409       | 3.30     | 4.79  | 2.29 |
| Hacker attacks on the system | OC | 3.066 | 3.066       | 3.03     | 4.39  | 2.10 |

*Security and Safety (S&S), Rules and Regulations (R&R), Pipeline Location (PL), Health Safety and Environment (HSE) and Operations Consent (OC)
Table 2. The results of analysing the RFs and testing the pipelines routs.

| RFs                                      | C       | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 |
|------------------------------------------|---------|---------|---------|---------|---------|---------|
| Terrorism, sabotage and the security risk | 5.43    | 0       | 0.00    | 1       | 5.43    | 1       | 5.43    | 0       | 0.00    | 0       | 0.00    |
| Stealing the products                    | 5.10    | 1       | 5.10    | 1       | 3.20    | 1       | 5.10    | 0       | 0.00    | 0       | 0.00    |
| Public awareness                         | 5.17    | 1       | 5.17    | 1       | 3.24    | 1       | 5.17    | 1       | 5.17    | 1       | 5.17    |
| Staff threats                            | 4.55    | 0       | 0.00    | 1       | 2.86    | 0       | 0.00    | 1       | 4.55    | 0       | 0.00    |
| Socio-political effects                  | 4.75    | 0       | 0.00    | 1       | 2.98    | 1       | 4.75    | 1       | 4.75    | 0       | 0.00    |
| Leakage of sensitive information         | 4.60    | 1       | 4.60    | 0       | 0.00    | 1       | 4.60    | 0       | 0.00    | 1       | 4.60    |
| Corruption                               | 2.69    | 1       | 2.69    | 1       | 3.30    | 1       | 2.69    | 1       | 2.69    | 1       | 2.69    |
| The absence of the law on TPD            | 2.46    | 1       | 2.46    | 1       | 3.02    | 1       | 2.46    | 1       | 2.46    | 0       | 0.00    |
| Lack of risk management practice         | 2.44    | 1       | 2.44    | 1       | 2.99    | 1       | 2.44    | 1       | 2.44    | 1       | 2.44    |
| Lack of proper training                  | 2.58    | 1       | 2.58    | 1       | 3.16    | 1       | 2.58    | 1       | 2.58    | 1       | 2.58    |
| Lack of risk registration                | 2.50    | 1       | 2.50    | 1       | 3.07    | 1       | 2.50    | 1       | 2.50    | 1       | 2.50    |
| Little research on this topic            | 2.46    | 1       | 2.46    | 1       | 3.03    | 1       | 2.46    | 1       | 2.46    | 1       | 2.46    |
| The geographical location                | 4.27    | 0       | 0.00    | 1       | 3.21    | 1       | 4.27    | 0       | 0.00    | 0       | 0.00    |
| The pipeline is easy to access           | 4.05    | 1       | 4.05    | 1       | 3.05    | 1       | 4.05    | 0       | 0.00    | 1       | 4.05    |
| Land ownership conflicts                 | 4.18    | 1       | 4.18    | 1       | 3.14    | 0       | 0.00    | 1       | 4.18    | 1       | 4.18    |
| Geological risks                         | 3.60    | 0       | 0.00    | 1       | 2.70    | 1       | 3.60    | 0       | 0.00    | 1       | 3.60    |
| Vehicles accidents                       | 3.18    | 0       | 0.00    | 1       | 2.39    | 1       | 3.18    | 0       | 0.00    | 1       | 3.18    |
| Animals accidents                        | 2.21    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    |
| Improper safety regulations              | 3.35    | 1       | 3.35    | 1       | 3.16    | 1       | 3.35    | 1       | 3.35    | 1       | 3.35    |
| Improper inspection and maintenance      | 3.34    | 1       | 3.34    | 1       | 3.15    | 0       | 0.00    | 0       | 0.00    | 1       | 3.34    |
| The risk related to the aboveground pipeline | 3.35  | 1       | 3.35    | 1       | 3.16    | 0       | 0.00    | 1       | 3.35    | 1       | 3.35    |
| Limited warning signs                    | 3.22    | 0       | 0.00    | 1       | 3.04    | 1       | 3.22    | 0       | 0.00    | 1       | 3.22    |
| Inadequate risk management               | 3.15    | 1       | 3.15    | 1       | 2.97    | 1       | 3.15    | 1       | 3.15    | 1       | 3.15    |
| Natural disasters                        | 2.81    | 1       | 2.81    | 0       | 0.00    | 1       | 2.81    | 0       | 0.00    | 1       | 2.81    |
| Corrosion                                | 2.58    | 0       | 0.00    | 1       | 3.17    | 1       | 2.58    | 1       | 2.58    | 0       | 0.00    |
| The weak ability to manage the risk      | 2.55    | 1       | 2.55    | 1       | 3.13    | 1       | 2.55    | 1       | 2.55    | 1       | 2.55    |
| Shortage of modern equipment             | 2.55    | 1       | 2.55    | 1       | 3.14    | 1       | 2.55    | 1       | 2.55    | 1       | 2.55    |
| Design, construction and material defects | 2.53    | 1       | 2.53    | 0       | 0.00    | 1       | 2.53    | 0       | 0.00    | 1       | 2.53    |
| Operational errors                      | 2.29    | 1       | 2.29    | 1       | 2.81    | 1       | 2.29    | 0       | 0.00    | 1       | 2.29    |
| Hacker attacks on the system             | 2.10    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    | 0       | 0.00    |

Sum = 100.00  F1= 64.12  F2= 78.50  F3= 80.27  F4= 51.29  F4= 66.55
4. Discussion
The initial list of RFs that affect the OGPs was identified based on the literature review and it was evacuated via a questionnaire survey. The participants were asked to add RFs that have not mentioned in the survey. After analysing their comments, the list of the affective RFs was revised. For instance, some of the RFs have been deleted from the list like the hacker attacks on the operating or control system and animals’ accidents as these RFs have a very low impact on the OGPs in Iraq based on the results of the survey. Some of the RFs like construction and material defects were split up into three RFs, which are design defects, construction defects and material defects. Some of the RFs were merged as one RFs like geographical location like "insecure areas" and the pipeline is easy to access. Some of the RFs added to the list like the pipes are older than the design age. Table 3 shows the final lists of RFs by their type.

Table 3. The final lists of RFs by their type.

| Groups                        | The RFs before the survey                          | The RFs after the survey                      | RF number |
|-------------------------------|--------------------------------------------------|---------------------------------------------|-----------|
| Security and Safety (S&S)     | Terrorism and sabotage                            | Terrorism, sabotage and the security         | 1         |
|                               | Thieves                                          | Thieves                                     | 2         |
|                               | Public’s Low legal and moral                      | Public’s Low legal and moral awareness      | 3         |
|                               | Staff threats                                     | Deleted                                     |           |
|                               | Socio-political such as poverty and               | Socio-political effects such as poverty and  |           |
|                               | Leakage of sensitive information                  | Leakage of sensitive information            |           |
| Rules and Regulations (R&R)   | Corruption                                        | Corruption                                  | 6         |
|                               | The law does not apply on the                     | The law does not apply on the saboteurs     | 7         |
|                               | Stakeholders are not paying proper attention      | Not paying proper attention to risk         | 8         |
|                               | Lack of proper training                           | Lack of proper training                      | 9         |
|                               | Lack of the accidents database and limited        | Lack of the accidents database and          | 10        |
|                               | researchers about this                            | Limited researchers about this              | 11        |
| Pipeline Location (PL)        | Geographical location like                        | Geographical location e.g. insecure zones   | 12        |
|                               | The pipeline is easy to access                    | Deleted                                     |           |
|                               | Conflicts over land ownership                     | Conflicts over land ownership               | 13        |
|                               | Geological risks such as                         | Geological risks such as groundwater and    | 14        |
|                               | Vehicles accidents                                | Deleted                                     |           |
|                               | Animals attacks on the pipeline                   | Deleted                                     |           |
| Health Safety and Environment (HSE) | Improper safety regulations                   | Improper safety regulations                 | 15        |
|                               | Improper inspection and                           | Improper inspection and maintenance         | 16        |
|                               | The above-ground pipeline increases sabotage and  | The above-ground pipeline increases         | 17        |
|                               | thefts                                           | sabotage and thefts opportunities           |           |
|                               | Limited warning signs                             | Deleted                                     |           |
|                               | Inadequate risk management                        | Natural disasters and weather               | 18        |
|                               | Natural disasters and weather                     |                                             |           |
| Operations Consent (OC)       | Corrosion and lack of corrosive                   | Corrosion and lack of corrosive protection  | 19        |
|                               | The weak ability to identify and                  | The weak ability to identify and monitor    | 20        |
|                               | Shortage of the IT services and                   | Shortage of the IT services and modern      | 21        |
|                               | Design, construction and material defects         | Construction defects (e.g. welding defects   | 22        |
|                               |                                                  | and damage the pipes during the             |           |
|                               |                                                  | Design defects                              | 23        |
|                               | Operational errors                                | Operational errors                          | 24        |
|                               | Hacker attacks on the operating or                | Deleted                                     |           |
| The added RFs after the       | The unqualified staff, lack of experience         | The unqualified staff, lack of experience    | 25        |
| survey                        | and not well educated about risk                  | and not well educated about risk            |           |
|                               | Pumping more than one type of petroleum product   | Pumping more than one type of petroleum     | 26        |
|                               | and crude oil from different fields               | product and crude oil from different fields |           |
|                               | Salts and metals contents in the transported      | Salts and metals contents in the transported| 27        |
|                               | External oil spots that negatively affect the     | External oil spots that negatively affect the| 28        |
|                               | Not taking the future urban planning into         | Not taking the future urban planning into    | 29        |
|                               | Poor quality pipes and material defects           | Poor quality pipes and material defects     | 30        |
|                               | The pipes are older than the design age           | The pipes are older than the design age     | 31        |
5. Conclusion

- The developed risk assessment tool in this paper provides a systematic approach of choosing safe routes for OGP projects, specifically for the organisations that just began analysing the RFs in OGPs more effectively, which is the case in OGP projects in Iraq.
- Using the FIS in risk assessment remedies the problems of the traditional approaches to risk analysis and ranking.
- It was found in Table 2 that Route 3 is the riskiest route (F3 = 80). Meanwhile, Route 4 is the safest route (F = 51). Therefore, the export gas pipeline should be built on this route.
- The initial list of the RFs has been identified from the literature review. This list has been revised after the survey based on analysing the participants’ comments about adding the RFs that affect the safety of OGPs in Iraq and did not mention in the survey.
- The future work of this paper is to estimate the consequences of OGPs failures. Moreover, evaluate the cost and time impact of the RFs; as well as, the cost and time impact of the risk mitigation methods that should be applied to mitigate them.
- The future work also includes analysing the probability, severity and RI of the added RFs. As well as, investigating their impact in the pipelines’ routes.

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Appendix A

Table 4: Questionnaire design (example)

| RF                          | What is the probability scale that the RFs threatening the OGP? | What is the severity scale of the flowing RFs? |
|-----------------------------|---------------------------------------------------------------|------------------------------------------------|
| s                           | Rare              | Unlikely | Possible | Likely   | Almost Certain | Negligible | Minor | Moderate | Major | Catastrophic |
| Terrorism and sabotage      |                   |          |          |          |                |            |       |          |       |               |
| Thieves                    |                   |          |          |          |                |            |       |          |       |               |
| Public’s Low legal and moral awareness |           |          |          |          |                |            |       |          |       |               |
| Staff threats               |                   |          |          |          |                |            |       |          |       |               |
| Socio-political such as poverty and education |           |          |          |          |                |            |       |          |       |               |

Appendix B

**Figure 3.** Participants’ information.

The response rate was 199 out of 400 (49.75%).