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# Investigation of the Risk Factors Causing Safety and Delay Issues in Oil and Gas Pipeline Construction Projects

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**Abstract**

Building the new Oil and Gas Pipelines (OGPs) without analyzing the potential Risk Factors (RFs) that influence the safety of these pipelines causes time and cost overrun in these projects. Quantifying the impact of the RFs on the duration of the projects is essential to provide an accurate estimate about the project duration and recognize the potential RFs that causing delay and safety issues in the projects. Identifying the RFs in the projects via literature review and analyzing their impact on the delivery time of the projects via a questionnaire survey and computer-based risk analysis model are the key methods adopted in the study. This study uses the Monte Carlo Simulation algorithm, which is integrated within @Risk Simulator to quantify the delay impact of the RFs. The @Risk simulator has the flexibility to integrated different risk distribution methods for each RF, which helps in overcoming the limitations of using ASTA Powerproject risk simulator to quantify the delay the projects, as done in a prior study. The @Risk simulator is useful in analyzing the delay in each task, working stage and overall project duration. The results provided by risk simulator is useful in understanding the sensitivity and the criticality of each RF that might cause delay issues in the projects. The outcomes of this study will help to the stakeholders, the decision-makers and the policy-makers of OGP projects to make sound decisions and enable them to take preventive actions of risk management while starting a new OGP project, which helps in minimizing the delay in the projects.



*Keywords:* Oil and Gas Pipelines; Risk Factors; Monte Carlo Simulation; @Risk; Delay; Time Overrun; New Projects; Construction Projects; Stakeholders Judgements; Compute Model

## 1. Introduction

Project management involves making schedules for project activities in order to monitor the project's time progress [1]. In the field of construction industry, delay is one of the most common problems in the majority of the projects in both developed and developing countries [2]. Delay may happen in every project during the construction stage, but it varies between the different projects and the different countries [3]. Understanding the delay factors and their level of impact on a project may help to avoid or minimize the project delay [4]. To do so, providing good knowledge about the Risk Factors (RFs) RFs and using analytical or simulation techniques are the most effective methods of risk assessment [5].

It is essential, therefore, to make an accurate check to quantify the impact of the RFs on the duration of new pipeline projects. This is because of the current results of risk assessment help in making the correct reactions and strategies towards the RFs during the planning and construction stages of projects, which will help in avoiding and/or minimizing the construction delay in these projects. Otherwise, these projects will be subject to delay problems, which have a significant impact on a country's economy.

Analyzing the impact of the RFs on the duration of the projects at the planning and design stage could help the stakeholders to make sound decisions in response to risk management to keep the delay interruption in the projects to a minimum, as much as possible. However, there is a lack of studies analyzing and quantifying the impact of the RFs on the duration of the projects in the developing countries, such as Iraq. Oil and Gas Pipelines (OGPs) in Iraq are some of the projects that significantly affected by the security situation of the country and suffering delay, which make the projects do not deliver at the targeted/planned time. Construction delay in OGP projects in Iraq obstructs the government's plans of increasing the oil and gas expert rate after 2003, which has a direct impact on the economic development and the economic situations of the country.

The aim of this paper, therefore, is to develop a Risk Management Framework (RMF) which will be used to identify, assess, and quantify the impact of the RFs associated with OGPs during the construction stage of these projects. The RMF will be used to quantify the delay impact caused by the delay and RFs and estimate whether or not the projects could be delivered on time.

## 2. Literature Review

The literature review revealed that several techniques could be used to analyze the risks in construction projects. For instance, checklists, interviews with the stakeholders, brainstorming, surveys and the Delphi technique. Some of these methods of risk and delay analysis are discussed below.

For example, C. Kog [6] identified and ranked the delay factors in construction projects in Portugal, the UK, and the US via examining 13 studies about the problem of construction delay in these countries. Kadry et al [7] used qualitative documents analyses to analyze the delay factors in construction projects in 16 countries with a high geopolitical risk. These two studies were limited to analyzing the delay factors in construction projects in the mentioned countries only. As well as, these studies did not make any assessment about the delay factors or quantify their impact on the projects. For example, they did not use any kind of survey, computer modelling or simulation methods to analyze the delay factors and quantify their impact on project duration.

R. Shah [8] identified the comparative delay factors in construction projects in countries such as Australia, Ghana and Malaysia via a questionnaire survey and recommended the potential measures to reduce their impact on the projects. This study has analyzed the possible minimum, the mean and the maximum duration of construction projects and the sensitivity of the work activities in these projects in the mentioned countries. Prasad et al. [9] used a questionnaire survey to identify and analyze the delay factors in transportation, power and water projects in India. Another questionnaire survey was carried out by Chiu and Lai [10] to analyze the frequency and the severity levels of the delay factors in the construction of electrical projects in Hong Kong. Mpofu [11] analyzed the delay factors in construction projects in the United Arab Emirates (UAE) via exploring the perceptions of the clients, the contractors and the consultants about the delay problem in their projects. Shebob et al. [4] analyzed the possible minimum, the mean and the maximum duration of a contraction project in Libya and the UK using Monte Carlo Simulation (MCS). However, the risk assessment methods used in these studies are limited to their regions of study, which means they cannot be effectively applied to analyze the impact of the delay factors in oil and gas projects and improve the level of safety of these projects elsewhere. Moreover, the oil and gas industry is complex by nature [12]. Oil and gas projects are recognized as highly technical projects by nature which are complex, have a high level of uncertainty, demand careful risk assessment and require appropriate risk management strategies [13]. Therefore, managing the RFs in such complex projects, like OGP projects, is difficult [14] and requires a high level of experience in risk management [15].

M. Fallahnejad [16] used document analysis and a questionnaire survey to identify the main delay factors and analyze their impact on pipeline projects in Iran. Similarly, Sweis et al. [17] used a questionnaire survey to identify the root causes of the delay factors in gas pipeline projects in Iran. Ruqaishi and Bashir [18] investigated the delay factors in the construction of oil and gas projects in Oman. Rui et al [19] carried out a comprehensive study to identify the RFs that affect the schedule of oil and gas projects in Nigeria. However, the risk assessment methods used in these studies are limited to their regions of study, which means they cannot be effectively applied to analyze the impact of the delay factors in oil and gas projects and improve the level of safety of these projects elsewhere particularly, where the projects are subject to different types of RFs such as security related risks.

In summary, the methods of delay assessments methods as discussed above (e.g. using the records, checklists, interviews, and surveys) are inactive to make an accurate estimation of the delay impact caused by the RFs in OGP project elsewhere. In other words, these methods cannot be used to analyze the delay in a developing and insecure country like Iraq because of a number of the following gaps in knowledge. For example, the records about delay and risk factors are either not available or not accessible in OGP projects in Iraq and the security level in Iraq is low, which makes the projects subject to different types of RFs particularly, the risks related to the security situations.

## 3. METHODOLOGY

The aim of this paper is to analyze the potential delay in a case study project caused by the associated RFs. The pipeline is going to be built in the south of Iraq. The length of the pipe is 164 km. It links Badra oil and gas field with the export point on the Gulf in Basra via Gharraf–An Nassiriyah, see Fig1. This project has been under planning since May 21, 2019 and the targeted delivery date is January 13, 2023. This means the overall duration of the project is estimated as 3 years and 238 days (1334 days) [20].

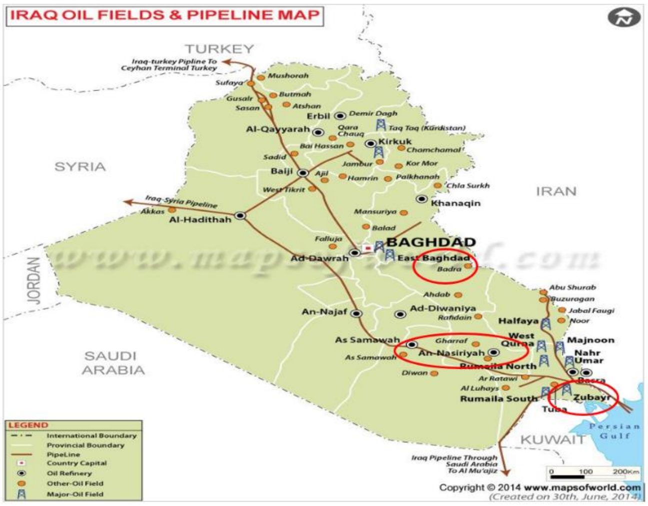


Fig. 1. Iraq oil fields and pipelines [33].

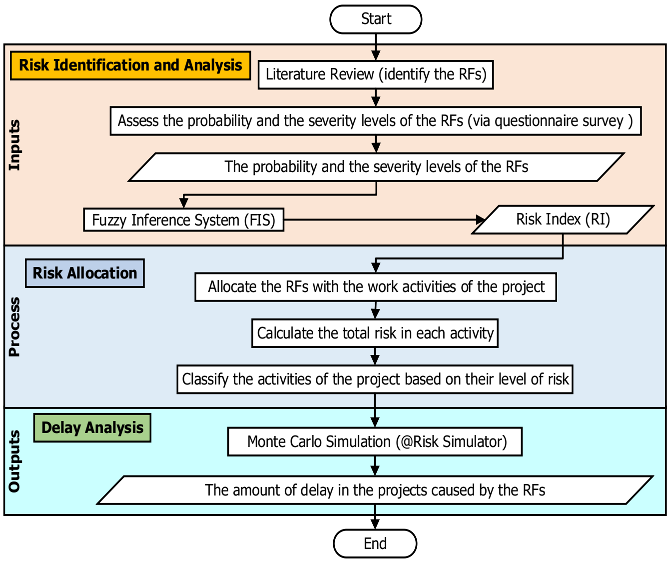


Fig. 2. The information flow chart of the Risk Management Framework (RMF) adopted in this paper.

As shown in the Fig 2 above, the RMF is structured under three main components: inputs (which is about risk identification and analysis), process (which is about calculate the risk level in the activities of the project) and outputs (which is about the amount of delay in the project), as described below.

1. **Inputs,** the RFs were identified via an extensive literature review about the risks in OGP projects worldwide [21,22]. The Risk Probability (RP) and Risk Severity (RS) levels of the RFs were assessed via conducting a questionnaire survey of the stakeholders in OGP projects in Iraq [23–25]. The results of the survey (i.e. the RP and RS levels of the RFs) were used as inputs for a computer-based risk assessment model, which used the fuzzy theory to calculate the Risk Index (RI) of the RFs [25,26]. Table 1 explains the identified RFs and their degree of impact on OGP projects in Iraq.

Table 1: The identified RFs and their degree of impact on OGP projects in Iraq (the inputs of the RMF).

| The findings of the literature review | The results of the survey | | The result of the FIS |
|---|---|---|---|
| RFs | RP* | RS^ | RI |
| Terrorism and sabotage | 3.995 | 4.490 | 3.99 |
| Corruption | 3.980 | 4.192 | 3.87 |
| Low public legal and moral awareness | 3.712 | 3.859 | 3.80 |
| Insecure areas | 3.717 | 4.106 | 3.76 |
| Thieves | 3.692 | 4.081 | 3.75 |
| Corrosion and lack of protection against it | 3.687 | 3.990 | 3.72 |
| Lack of proper training | 3.646 | 3.773 | 3.71 |
| Improper safety regulations | 3.687 | 3.949 | 3.70 |
| Exposed pipelines | 3.667 | 3.682 | 3.70 |
| Improper inspection and maintenance | 3.227 | 3.924 | 3.69 |
| Conflicts over land ownership | 3.495 | 3.611 | 3.68 |
| Shortage of IT services and modern equipment | 3.667 | 3.652 | 3.68 |
| Weak ability to identify and monitor the risks | 3.631 | 3.899 | 3.67 |
| Design, construction and material defects | 3.333 | 3.848 | 3.64 |
| Lack of risk registration | 3.566 | 3.697 | 3.60 |
| Easy access to pipeline | 3.631 | 3.646 | 3.57 |
| Limited warning signs | 3.626 | 3.571 | 3.56 |
| Little research on this topic | 3.621 | 3.697 | 3.55 |
| Lawlessness | 3.606 | 3.682 | 3.54 |
| Stakeholders not paying proper attention | 3.530 | 3.143 | 3.51 |
| Public poverty and education level | 3.449 | 3.409 | 3.49 |
| Inadequate risk management | 3.227 | 3.505 | 3.48 |
| Leakage of sensitive information | 2.980 | 3.505 | 3.38 |
| Threats to staff | 3.323 | 3.399 | 3.35 |
| Operational errors | 3.101 | 3.611 | 3.30 |
| Geological risks | 2.747 | 3.182 | 3.17 |
| Natural disasters and weather conditions | 2.652 | 3.066 | 3.10 |
| Hacker attacks on the operating or control systems | 2.237 | 2.970 | 3.03 |
| Vehicular accidents | 2.465 | 2.712 | 2.80 |
| Animal accidents | 1.894 | 2.020 | 1.95 |

*In the survey, the probability level of the RFs were calculated using Five-points Likert Scale, as follows (Almost certain, Likely, Possible, Unlikely and Rare) (23).
^ In the survey, the severity level of the RFs were calculated using Five-points Likert Scale , as follows (Catastrophic, Major, Moderate, Minor and Negligible) (23).

The results of the survey and the computer-based risk assessment model indicated that terrorism and sabotage, corruption, low public legal and moral awareness, insecure areas and thieves are the most critical RFs that affect the safety of OGP projects in Iraq. On other hands it was found that the RFs that have the less impact on the projects are geological risks, natural disasters and weather conditions, hacker attacks on the operating or control systems, vehicular accidents and animal accidents.

2. **Process**, the process part of the RMF focuses on calculating the risk levels of the project activities as follows.

*2.1. Allocating the RFs to the project activities.* The RFs were allocated to the work activities depending on the type of RF and the nature of the activity. Professional knowledge was used to achieve this task. The subjective and objective analysis of a technical report [27] was used to justify the process of risk allocation because it explained what was required in each activity, the nature of each activity and the potential RFs that could affect that activity based on vast experience and a review of the construction of OGP projects worldwide.

*2.2. Calculate the Total Activity Risk (TAR) each activity using equation 1.*

The TAR calculates the summation of the RI values of the RFs allocated to the project activities.

$$\boldsymbol{TAR\ of\ an\ activity = \sum RI\ of\ the\ relevant\ RFs\ to\ the\ activity} \quad \text{(Equation 1)}$$

*2.3. Calculate the Total Activity Risk Ratio (TARR) of the activity from 100% using equation 2.*

$$TARR\ (100\%) = \frac{The\ total\ risk\ of\ an\ activity}{\sum Total\ risk\ of\ the\ project\ X\ 100\%} \quad \text{(Equation 2)}$$

*2.4. Classify the project activities based on their level of risk as follows.*

2.5. The activities with [0-1] total risk were considered as Very Low (VL) risk activities; the activities with [1-2] total risk have a Low (L) risk; those with [2-3] total risk have a Moderate (M) risk; those with [3-4] total risk have a High (H) risk; and those with [4-5] total risk have a Very High (VH) risk. Based on the risk level of the activity, this paper has set up five different levels of risk variation on the duration of the project as shown in Table 2.

Table 2: The total risk and risk levels of the project's main working activities.

| Activities | Equation 1 | Equation 2 | Risk Level | The impact level on the duration of the project |
|---|---|---|---|---|
| Concept and definitions | 18.11 | 0.86 | VL | 95% - 105% |
| Life-cycle plan | 71.8 | 3.41 | H | 80% - 120% |
| Choosing the route | 76.65 | 3.64 | H | 80% - 120% |
| Route approval | 73.14 | 3.47 | H | 80% - 120% |
| Design and development | 43.44 | 2.06 | M | 85% -115% |
| Installation procedure | 29.28 | 1.39 | L | 90% - 110% |
| Risk assessment | 49.67 | 2.36 | M | 85% -115% |
| Time schedule | 22.08 | 1.05 | L | 90% - 110% |
| Cost estimation | 22.08 | 1.05 | L | 90% - 110% |
| Communications | 25.43 | 1.21 | L | 90% - 110% |
| Materials order | 18.41 | 0.87 | VL | 95% - 105% |
| Survey, staking and setting out | 75.77 | 3.60 | H | 80% - 120% |
| Clearing and grading the right-of-way | 73.46 | 3.49 | H | 80% - 120% |
| Topsoil stripping | 57.88 | 2.75 | M | 85% -115% |
| Buildings, roads and river crossings | 76.63 | 3.64 | H | 80% - 120% |
| Pipe transportation to site | 59.02 | 2.80 | M | 85% -115% |
| Temporary fencing and signage | 51.09 | 2.43 | M | 85% -115% |
| Trenching | 54.05 | 2.57 | M | 85% -115% |
| Temporary erosion control and side support | 57.48 | 2.73 | M | 85% -115% |
| Pipe set-up | 43.84 | 2.08 | M | 85% -115% |
| NDT tests | 32.77 | 1.56 | L | 90% - 110% |
| Welding, fabrication and installing | 36.28 | 1.72 | L | 90% - 110% |
| Sandblast | 32.82 | 1.56 | L | 90% - 110% |
| Painting | 32.81 | 1.56 | L | 90% - 110% |
| Coating | 54.69 | 2.60 | M | 85% -115% |
| Lowering pipe and backfilling | 46.71 | 2.22 | M | 85% -115% |
| Cathodic protection of the pipe | 68.64 | 3.26 | H | 80% - 120% |
| Final fitting | 32.61 | 1.55 | L | 90% - 110% |
| As-built survey | 32.48 | 1.54 | L | 90% - 110% |
| Hydro, pressure test | 29.1 | 1.38 | L | 90% - 110% |
| Backfilling | 36.16 | 1.72 | L | 90% - 110% |
| Fencing and signage | 61.49 | 2.92 | M | 85% -115% |
| Final clean-up | 40.11 | 1.90 | L | 90% - 110% |
| Right-of-way reclamation | 54.03 | 2.57 | M | 85% -115% |
| Safety barriers | 55.53 | 2.64 | M | 85% -115% |
| Operation within design limits | 97.54 | 4.63 | VH | 75% - 125% |
| Commissioning operation value | 97.54 | 4.63 | VH | 75% - 125% |
| Measure the performance and efficiency | 29.26 | 1.39 | L | 90% - 110% |
| Enhanced performance and efficiency | 97.54 | 4.63 | VH | 75% - 125% |
| Monitoring and inspection | 42.57 | 2.02 | M | 85% -115% |
| Maintenance | 59.54 | 2.83 | H | 80% - 120% |
| Risk control | 36.31 | 1.72 | L | 90% - 110% |

3. **Outputs**, this section explains how Monte Carlo Simulation (MCS) works to simulate the impact RFs on the duration of the project. After allocating the RFs to the work activities of the project, MCS will calculate the duration of each activity by applying the iterations between the minimum and maximum duration of the using @Risk Simulator. The initial planned duration of the project was 3 years and 238 days (1334 days). After analyzing the potential RFs that affect the work activities of the project, it was found that the average delay in the project is 1374.94 days, which means the delay in the project is 40.94 days, see Fig 3.

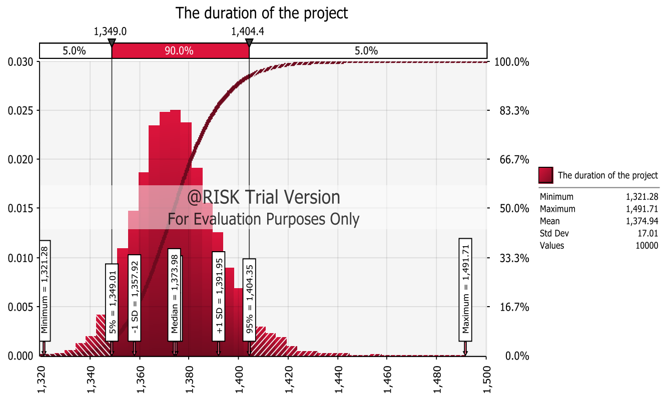


Fig. 3. The results of simulating the duration of the project.

Moreover, @Risk could be used to analyze the delay in the duration of the individual activities of the project after considering the impact of the associated RFs. The results revealed that the activities with the highest delay in the project are the hydro and pressure test, the as-built survey, the trenching activity, the cathodic protection of the pipe, the temporary fencing and signage and of the sand blast activities, with a potential delay of 142.07 days, 137.04 days, 80.17 days, 57.62 days, 53.71 days and 47.88, respectively (see Table 3).

## 4. Findings and Discussion

In conditions of data scarcity, the RFs will be mainly identified based on the literature review. Therefore, the RFs in OGP projects were identified based on an extensive and worldwide literature review about the risks that affect the safety of the pipelines. Based on the investigations of literature review, thirty RFs were identified in the projects and. The findings of the literature review in order to overcome the problem of data scarcity about the RFs in OGP projects in Iraq, which represent the first finding and contribution of this paper.

The second finding and contribution of this paper come from analyzing the RP and RS levels of the RFs based on a questionnaire survey that reflect the reality of the problems after engaging with the stakeholders in the projects. However, there is a potential problem associated with assessing the RFs depending on the stakeholders' judgement only, as they may not always yield to a consistent and accurate ranking of the RFs [28]. This is because the stakeholders have different views of the impact levels of the RFs [29].

Table 3: The duration and the potential delay of the activities of the project.

| Activity | Planned duration (day) | Median (day) | Delay (day) = median – planned duration |
|---|---|---|---|
| Concept and definitions | 60 | 81.82 | 21.82 |
| Life-cycle plan | 60 | 82.56 | 22.56 |
| Choosing the route(s) | 90 | 136.40 | 46.40 |
| Route(s) approval | 90 | 128.53 | 46.4 |
| Design and development activity | 90 | 123.65 | 38.53 |
| Manufacturing and installation (procedure/plan) | 30 | 54.10 | 33.65 |
| Risk assessment and management plans | 90 | 128.56 | 24.1 |
| Time schedule | 45 | 61.24 | 38.56 |
| Staking for construction and communications | 30 | 61.24 | 31.24 |
| Survey, staking and setting out | 5 | 42.35 | 37.35 |
| Materials order activity | 30 | 6.01 | -23.99 |
| Clearing and grading the Right-Of-Way (ROW) | 30 | 41.71 | 11.71 |
| Topsoil stripping and front-end grading | 30 | 43.12 | 13.12 |
| Buildings, roads and rivers crossings | 45 | 42.95 | -2.05 |
| Temporary fencing and signage | 7 | 60.71 | 53.71 |
| Pipe transporting to sit | 90 | 22.43 | -67.57 |
| Trenching | 60 | 140.17 | 80.17 |
| Temporary erosion control and side support | 60 | 83.07 | 23.07 |
| Pipe set-up | 99 | 91.73 | -7.27 |
| Welding, fabrication and installing pipe | 100 | 143.91 | 43.91 |
| NDT tests | 100 | 147.66 | 47.66 |
| Sand blast | 100 | 147.88 | 47.88 |
| Painting | 100 | 147.72 | 47.72 |
| Cathodic protecting the pipe | 90 | 147.62 | 57.62 |
| Coating | 100 | 131.84 | 31.84 |
| Lowering pipe in and backfilling | 100 | 147.79 | 47.79 |
| As-built survey | 10 | 147.04 | 137.04 |
| Final fitting | 100 | 14.28 | -114.28 |
| Hydro pressure test | 5 | 147.07 | 142.07 |
| Backfilling | 30 | 6.04 | -23.96 |
| Fencing and signage | 14 | 41.65 | 27.65 |
| Final clean-up | 21 | 17.19 | -3.81 |
| Right-of-way reclamation | 29 | 28.31 | -0.69 |
| Safety barriers | 29 | 38.42 | 9.42 |
| Fencing and signage | 41 | 70.79 | 29.79 |

Moreover, assessing and ranking the RFs in the projects based only on the results of the survey could cause inaccurate ranking of the RFs. For example, an RF with a high value of RS could still be considered as a critical RF that needs to be dealt with a matter of urgency. However, the same RF could not come at the top of the ranking if it had a low RP. This is similar if the RP of the RF is high and the RS is low, which is one of the limitations of the traditional risk assessment methods. Therefore, in order to reduce the uncertainty associated with analyzing the RFs, the calculation of the degree of impact of the RFs on the OGP projects will be performed using the fuzz theory [30]. The fuzzy uses approximate ranges rather than exact values of processing and controls. In other words, the use of ranges of very low, low, moderate, high and very high risk, the interpolation between these ranges, and the aggregate results of RP and RS of the RFs have helped in reducing the uncertainty of calculating the RI values of the RFs, which represent the third finding and contribution of this paper [31].

After identifying the RFs that might affect the safety of the pipelines and analyzing their degree of impact on the projects, this paper has allocated the RFs to activities of the projects based on the nature of the RFs and the activities. Then, equation 1 and 2 were used to calculate the amount of risk and level of risk in each activity of the project. This represent the fourth finding and contribution of this paper, which help the stakeholders in the projects to identify the RFs and activities that have the highest impact on the duration of the project.

MCS integrated with @Risk simulator was used to quantify the delay impact of the RFs on the duration of the project. The results of MCS explained that the minimum and maximum duration of the project are 1329.30 days and 1441.84 days, respectively. The project has a 5% chance of being completed between 1329.30 and 1349.1 days or between 1404.5 days and 1441.84 days. The project has a 90% probability of being finished between 1349.1 days and 1404.5 days. The median duration of the project is 1374.94 days, which means that the project has a 50% probability of being completed in this duration, which means the delay in the project is 40.94 days, see Fig 3, which is the main finding of this paper.

@Risk simulator helps to apply different distribution methods for each RF and activity at the same time, which will enhance the risk simulation results and add more confidence regarding the project completion probability. Applying different risk simulation methods for risk simulation make the results of risk analysis different. For example, [32] used MCS integrated with ASTA Powerproject software to analyze the RFs that cause delay in the same project. ASTA Powerproject has only four methods of risk distribution (which are uniform, normal, skewed normal and skewed triangular distribution), but only one distribution method could be applied on time during the process of risk simulation, which does not reflect the reality of the RFs on the duration of the projects. As different RFs have different impact of the activities of the projects. This is one of the limitations of using ASTA Powerproject quantifies the impact of the RFs on the duration of the projects. As well as, ASTA Powerproject software could not be used to analyze the delay in the different stages of the projects.

In summary, compared to the ASTA Powerproject, @Risk simulator is a more useful and powerful tool to analyze the RFs and the project delay. This is because @Risk can use more and different risk distribution methods than ASTA. Moreover, it could be used to analyze the delay in the duration of the individual activities, by the stages of the projects and by the overall duration of the projects. Meanwhile, the ASTA risk simulator is useful to analyze the delay that affects the overall duration of the projects only. Table 4 summarizes the results of the ASTA Powerproject and the @Risk simulator.

Table 4: The difference in using the ASTA risk simulator and the @Risk simulator to analyse the delay in the project.

| Program | Results (delay) | Reference |
|---|---|---|
| ASTA risk simulator | 14 – 15 days (using four different distribution methods) | [32] |
| @Risk simulator | 41 days | This study |

The difference in the results of ASTA and @Risk is because the ASTA Powerproject applies one risk distribution method for all RFs and project activities at a time, which makes the RFs and the project activities give the same impact regarding the duration of the project, which is not accurate. On the other side, the @Risk Simulator applies different risk distribution methods for the RFs and the project activities, rather than one distribution method at a time, with a degree of impact on the duration of the project. For example, Risk Triang (0,0.7,1) distribution was assigned to the stealing the products and the materials RFs, which is different from assigning Uniform, Normal, Triangular or Skewed Triangular with no degree of impact on the duration of the project, as done in ASTA [32]. Assigning different risk distribution methods for the RFs and the project activities with a degree of impact on the duration of the project was the reason behind the difference in the results of ASTA and @Risk.

## 5. CONCLUSION

After considering the impact of the RFs on the duration of the project, it was found that the potential delay in the project is 41 days. The activities that have the highest impact on the duration of the project are hydro and pressure test, the as-built survey, the trenching activity, the cathodic protection of the pipe, the temporary fencing and signage and of the sand blast activities. The advantage of using the @Risk simulator rather than the ASTA risk simulator is that the @Risk simulator has more flexibility in applying different risk distribution methods for the same RFs and work activities at the same time. Additionally, the @Risk simulator could help the researchers to analyze the delay by the activities of the project, which could not been done using the ASTA risk simulator.

This research has developed a systematic and integrated RMF, which was useful to quantify the delay impact in the OGP projects. The RMF designed in this study was used to provide a wide range of knowledge about identifying the RFs and analyzing their impact on OGP projects is a systematic and accurate way. The RMF that designed in this paper is a useful tool that could be used to analyze the construction delay in OGP during the planning and design stage of these projects.

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