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Article

Achieving successful gas plant construction: A risk modelling framework with quantitative risk-based approach to schedule management

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Abstract: The construction of gas plants often experiences delays caused by various factors, which can lead to significant financial and operational losses. This research aims to develop an accurate risk model to improve the schedule performance of gas plant projects. The model uses Quantitative Risk Analysis (QRA) and Monte Carlo simulation methods to identify and measure the risks that most significantly impact project schedule performance. A comprehensive literature review was conducted to identify the risk variables that may cause delays. The risk model, pre-simulation modeling, result analysis, and expert validation were all developed using a Focused Group Discussion (FGD). Primavera Risk Analysis (PRA) software was used to perform Monte Carlo simulations. The simulation output provides information on probability distribution, histograms, descriptive statistics, sensitivity analysis, and graphical results that aid in better understanding and decision-making regarding project risks. The research results show that the simulated project completion timeline after mitigation suggested an acceleration of 61–65 days compared to the findings of the baseline simulation. This demonstrates that activity-based mitigation has a major influence on improving schedule performance. This research makes a significant contribution to addressing project delay issues by introducing an innovative and effective risk model. The model empowers project teams to proactively identify, measure, and mitigate risks, thereby improving project schedule performance and delivering more successful projects.

Keywords: gas plant; monte carlo simulation; project risk management; schedule performance; quantitative risk analysis

1. Introduction

The key objective of this research is to contribute to the advancement of oil and gas project management by developing a comprehensive risk modeling framework. This framework aims to provide a structured approach for identifying, assessing, and mitigating potential risks throughout the project lifecycle. By enabling more informed decision-making, optimizing resource allocation, and enhancing overall project performance, this research seeks to improve the efficiency, effectiveness, and profitability of oil and gas construction projects.

Oil and gas construction projects have high complexity and risk due to the dynamic work environment, large investment value, diverse stakeholders, technological complexity, and the unique nature of the industry (Van Thuyet et al., 2007). The project scale is relatively higher than other construction projects (Kang and Kim, 2016). Gas plant construction projects often experience disruptions that frequently lead to schedule delays and cost overruns, primarily due to various risks arising from project complexity, broad scope, and stringent requirements for high-quality materials and equipment (Jang et al., 2015). The gas plant construction project life cycle is commonly segregated into conceptual design, preliminary design, detailed design, construction and testing, commissioning, and handover. Understanding the importance of the critical activities in the construction phase of the oil and gas project is important to optimize the outcome of the whole project to be delivered within schedule, budget, and quality (Umeesh et al., 2020). Gas plant construction is a complex undertaking involving numerous interconnected stages. The level of complexity can vary significantly. Larger plants with higher capacities often involve more intricate designs, equipment, and infrastructure. Different types of gas (e.g., natural gas, biogas) may require specialized processing techniques, leading to varying levels of complexity. Construction in remote or challenging environments, such as offshore locations or areas with unstable soil, can introduce additional complexities. Compliance with local, national, and international regulations can impact the design, construction, and operation of gas plants (Ferreira et al., 2023; Ni et al., 2022).

The use of advanced technologies and automation can simplify certain aspects of construction but may also introduce new challenges. The intricate network of pipes, valves, and equipment requires precise installation and alignment to ensure efficient and safe operation. Gas plants handle flammable and potentially hazardous substances, making safety a paramount concern. Adhering to strict environmental regulations can also add complexity. Implementing sophisticated control systems to monitor and regulate the plant’s operations requires careful planning and integration. Ensuring that all components and systems meet high-quality standards is essential for the plant’s long-term reliability and performance. Managing the numerous stakeholders, subcontractors, and suppliers involved in gas plant construction requires effective project management and coordination (Jang et al., 2015; Shebl et al., 2023).

To address these complexities, gas plant projects often involve a multidisciplinary team of engineers, technicians, and other experts. Advanced planning, rigorous quality control, and effective risk management are crucial for successful gas plant construction.

The increasing global energy demand is driving a growing need for reliable risk assessment models for oil and gas projects that can provide adequate and accurate data for policy planning (Aven et al., 2007). Projects always face uncertainties due to both external and internal factors. Therefore, risk management is necessary to reduce the likelihood of occurrence and/or negative effects of risk events (Fan et al., 2008). Due to the increasing scale of projects and the growing sophistication of systems to meet user needs and keep pace with the latest technological advancements, the role of risk management in large-scale projects will become increasingly crucial. At various phases of oil and gas projects, many risks may arise. These risks have the potential to impact schedule, quality, cost, environment, and safety, leading to significant losses or severe fatal accidents (Xu et al., 2018). Thus, neglecting the risks might result in increased expenses and delays, as well as project failure (Zhang and Fan, 2014).

Currently, there is a deficiency in the activities of gas plant construction projects, particularly in Indonesia. This deficiency lies in the absence of a risk model guideline for project organizers to create accurate plans. However, the design of this risk model is not without its challenges, which may arise during the research process and the application of the research results to the subject of study. The following are some of the identified problems based on the literature review of previous scholars. (1) There's no standardized risk model for gas plant construction projects in Indonesia (Hatmoko and Khasani, 2020). (2) Without a risk model, project organizers struggle to create precise plans (Dedasht et al., 2017). (3) Developing a risk model comes with its own set of difficulties during the research phase. (4) Even after developing the model, applying it to real-world projects can be problematic (Nasirzadeh et al., 2014). The risk management analysis approach taken by practitioners and companies involved in similar gas plant construction projects often relies solely on qualitative methods. As a result, the measurement of the impact of risks on project success parameters, particularly time, is less accurate. The increasing global demand for energy is driving the need for a reliable risk assessment model for oil and gas projects. This model should provide adequate and accurate data to support policymaking.

Risk management in the energy sector, particularly in the oil and gas industry, and infrastructure megaprojects has been the subject of numerous studies in recent years. Khadem et al. (2018) provided a Monte Carlo simulation-based quantitative risk assessment for an Oman gas injection project. Wang et al. (2018) proposed a hybrid fuzzy multicriteria decision-making method to rank the risk variables for projects including energy performance contracts. The suggested method takes into account the interdependence of the criteria as well as the decision-maker's limited rationality and behavioral psychology. Kassem et al. (2019) evaluated how external risk factors affected Yemen's major oil and gas construction projects' success. Dehghan et al. outlined a risk-analysis procedure and the outcomes of the application of probabilistic risk-analysis techniques to the new Iranian upstream contract framework for a real-world gas megaproject (Dehghan et al., 2022). Nabawy and Khodeir (2020) conducted a systematic review of the quantitative analysis literature in the construction of worldwide mega projects with the primary objective of enhancing the quantitative risk analysis practices of contractors in the presence of uncertainty. Hermawan et al. (2024) offered project stakeholders a comprehensive knowledge of the risk landscape in gas plant projects from the project owner's perspective, enabling them to navigate the complex web of issues and guarantee the success of the project. Guan et al. (2018) concluded that the risk assessment methods of qualitative or semi-quantitative risk assessment cannot guarantee the safety of high-risk oil and gas drilling. Therefore, it is necessary to establish a quantitative oil and gas drilling risk assessment method. Meanwhile, Mandal and Agarwal (2023) offered an outline of the general principles and criteria for risk management in oil and gas projects. The study also examines upcoming trends in QRA assessment approaches.

This paper aims to propose and develop a more accurate and detailed risk model using quantitative risk analysis methods in Indonesian gas plant projects. This work may also serve as a case study for the oil and gas industry in adjacent nations in the same region with comparable political, cultural, and environmental systems. By using an accurate risk model, the impact of risks on project time performance can be predicted more precisely. By considering the risks associated with gas plant projects and estimating their impact on project time performance, the developed risk model can assist in making more effective decisions in managing risks and improving resource utilization efficiency. By using an accurate risk model, appropriate decisions can be made and overall project performance can be optimized. This can help ensure that the gas plant project can be completed effectively, and efficiently and achieve the desired business objectives.

The Monte Carlo simulation approach is being used for this risk modeling. The results should give an overview of the distribution and sensitivity of uncertainty components to risks that may arise during the construction of gas plants. The first step in the modeling method is to identify the variables that are relevant by first figuring out which factors have an impact on the risk under analysis, and then figuring out the probability distribution of each variable. The next action is to develop a model that explains how these variables relate to one another. Next, use the developed model to calculate the outcome by running a Monte Carlo simulation using samples from the probability distribution for each variable. The probability distribution of the outcome, or the Monte Carlo simulation's findings, must be analyzed at the following stage. Finally, analyze the data and make the necessary adjustments. The outcomes will be useful for planning, making decisions, or creating risk-reduction strategies.

QRA is a risk analysis method that uses quantitative measurement techniques to evaluate the impact and probability of a risk occurring (Steyn, 2018). This method can provide a clear and accurate picture of the risks faced by an organization. The basic principles of QRA are based on two fundamental principles, (1) Likelihood, and (2) Impact. By combining these two principles, the QRA method can produce a quantifiable risk value. The QRA method consists of the following steps: Identifying all risks that can affect the project; assessing the likelihood of each risk occurring; assessing the impact of each risk if it occurs; calculating the risk value by multiplying the likelihood by the impact; and developing a plan to address the risk.

QRA can be applied in oil and gas projects to assess technical, commercial, environmental, and political risks. One commonly used method in oil and gas project QRA is Monte Carlo Analysis. This method models various risk variables in the project using probability distributions. Monte Carlo generates many simulations based on different risk variables and then calculates the probability distribution of project outcomes. This allows for a comprehensive assessment of the risks and opportunities in the project (Brandimarte, 2014).

A risk model is a mathematical or graphical representation used to describe the potential risks that may occur in a situation or project. A risk model can also be called an abstract representation of a system that can be used to understand, analyze, and manage risks. Risk models help stakeholders understand and manage various risks that may affect the achievement of desired goals or outcomes. Creating a comprehensive risk model is especially important for megaprojects because, due to their structural complexity, these projects not only experience an increased number of risks but also complex and uncertain ones (Boateng et al., 2015). Inadequate risk models can be produced due to poor conceptualization of risk-related characteristics, including complexity and uncertainty, which will undermine public confidence in the usefulness of risk management (Erol et al., 2022). Risk models can be used to compare different options and select the one that best suits the objectives and risk tolerance.

Risk modeling is an approach used to predict and manage future risks using specialized modeling techniques. This method combines historical data, statistical analysis, and mathematical modeling techniques to predict the likelihood of risk events organization (Erfani and Cui, 2022). Monte Carlo simulation is frequently chosen for

QRA in oil and gas projects due to its ability to incorporate numerous complex risk variables and generate more accurate probability distributions of project outcomes. Monte Carlo is often used because of its flexibility in handling uncertainties and complexities of risks in oil and gas projects (Brandimarte, 2014). This enables management to gain a better understanding of the potential risks and opportunities in the project, allowing them to make more informed decisions. Although it requires powerful software and computing, available Monte Carlo software has made it easier to implement in modern oil and gas projects.

In Monte Carlo Analysis, a mathematical or statistical model is created to describe the system or process being analyzed, and then data on the variables that affect the system or process are entered into the model. This data is then iterated to generate various possible outcomes that may occur in the system or process. The results obtained are calculated by performing thousands or millions of random iterations on the created model. Each iteration is generated by taking a random value from each input variable in the model and then using the model to calculate the possible outcome. With more simulations performed, the results of the Monte Carlo analysis will be closer to the actual value (Brandimarte, 2014). The advantage of Monte Carlo Analysis is that it allows users to estimate the likelihood of outcomes of a complex and variable process or event. Monte Carlo Analysis allows users to assess risks and take appropriate actions to mitigate those risks. This method is widely used in finance, project planning, investment evaluation, and other risk analyses.

The following are some things to consider when performing Monte Carlo Analysis (Brandimarte, 2014):

a. The selection of the correct input variables is important in performing Monte Carlo Analysis. The input variables selected must truly affect the outcome and have a measurable probability distribution.
b. The model created must account for all relevant input variables and factors that affect the outcome. The model must also be accurate in estimating the probability distribution of the outcome.
c. The number of iterations required to obtain accurate results will depend on the complexity of the model and the number of input variables selected.
d. The results of the Monte Carlo Analysis should be carefully analyzed to understand the risks and decisions that need to be made.

2. Materials and methods

This research goal will be addressed by doing a literature review, document analysis, and data gathering (top risk register, schedule level 3), conducting a Focused Group Discussion (FGD) to develop the risk model, pre-simulation modeling, Monte Carlo simulation using Primavera Risk Analysis (PRA) software, and analysis of results and expert validation. The FGD will involve project executors from various departments at the Manager, Assistant Manager, Supervisor, and Senior Engineer/Senior Analyst levels with a minimum of 10 years of experience in similar projects. The following step is pre-simulation modeling, which involves distributing risk probabilities and time as well as setting the maximum and minimum durations of each activity. The results of the pre-simulation would then be simulated using the Monte Carlo approach.

Monte Carlo simulation is a statistical method that employs repeated random sampling to estimate numerical results. By creating a model of a complex system and generating random inputs, the simulation can be run multiple times to analyze the potential outcomes. This technique is widely used in fields such as finance, engineering, physics, and healthcare to model uncertainty, assess risk, and optimize decision-making (Brandimarte, 2014). While it can be computationally intensive for large-scale simulations, Monte Carlo simulation offers a valuable approach to understanding complex systems and making informed predictions.

Monte Carlo simulation consists of approximating some property of a huge number of things by averaging the value of that property for N of these things chosen randomly among all the others. It is a technique to approximate the expectation of random variables using samples. It can be defined mathematically with the following formula:

$$E(X) \approx \frac{1}{N} \sum_{n=1}^{N} x_n$$

The mathematical sign $\approx$ means that the formula on the right inside of this sign only gives an approximation of what the random variable *X* expectation *E*(*X*) is. Note that in a way, it's nothing else than an average of random values. Monte Carlo methods are a class of computational algorithms that use repeated random sampling to solve problems. They are often used to model phenomena with significant uncertainty in inputs, such as calculating the risk of gas plant projects. In project management, Monte Carlo analysis can be used to estimate project timelines and costs, assess cost risks, and optimize resource allocation. It can also help identify areas of concern or high-impact risks.

PRA is a powerful software capable of effectively analyzing data for extracting reliable outputs for cost and schedule analysis. Its core functionality is Monte Carlo simulation, a robust statistical method that can handle complex project scenarios with uncertainty. By running thousands of iterations, it provides a comprehensive understanding of potential outcomes. PRA also supports a variety of probability distributions to accurately represent the uncertainty associated with different activities. It effectively handles dependencies between activities, ensuring that changes to one task's duration or cost impact related tasks accordingly. This software allows for the creation of multiple scenarios to explore different project outcomes under varying conditions. The sensitivity analysis feature helps identify which factors have the most significant impact on the project's cost or schedule. PRA can be used to identify potential risks, assess their impact, and develop mitigation strategies.

The Monte Carlo simulation process begins by defining the risk variables to be tested and the appropriate probability distribution for each variable. Then, sample values are drawn from each probability distribution. Each sample value is then used to calculate the desired outcome or output. Several experts have identified different types of risks in the oil and gas industry. **Table 1** shows the types of such risks.

Table 1. Type of risks in oil and gas projects.

Type of Risks	Remarks	Sources
Technical	Oil and gas projects often involve advanced technologies such as deep-sea drilling or extracting oil and gas from hard-to-reach fields. Technical risks encompass engineering miscalculations, construction problems, equipment failures, structural damage, and the inability to achieve desired results.	(Khadem et al., 2018)
Geological	Variability in reservoirs, pressure, and hydrocarbon distribution can affect productivity and project outcomes.	(Balas, 2023)
Oil and Gas Price	Unstable market conditions can render projects uneconomical or reduce expected profits.	(Dehghan et al., 2022)
Regulatory Compliance	Violations of regulations can result in legal sanctions, fines, or even project delays or shutdowns.	(Cheng et al., 2019)
Environmental	These risks include oil spills, water pollution, and other environmental issues that can have long-term impacts on ecosystems.	(Basak et al., 2021)
Supply and Logistics	Reliance on critical supplies, such as drilling equipment or fuel, can create risks if supplies are disrupted or delayed.	(Kassem et al., 2019)
Financial	These include risks related to project costs exceeding budgets, payment delays, currency fluctuations, and other financial issues that can affect project profitability.	(Dehghan et al., 2022)
Political	Changes in government, political instability, and conflicts can disrupt operations and investments.	(Basak et al., 2021)
Health, Safety, and Security	Worker safety is a top priority in the oil and gas industry. HSE risks include workplace accidents, injuries, and even fatalities.	(Basak et al., 2021)
Market	This involves changes in global supply and demand for oil and gas.	(Kassem et al., 2019)

Source: Various papers.

The flowchart of the research process can be seen in **Figure 1**.

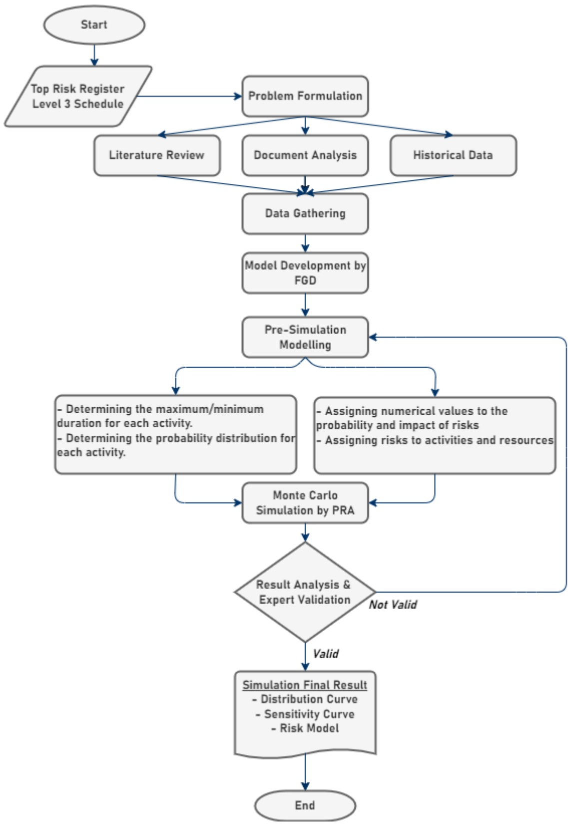


Figure 1. Research process flow chart.

Source: Researcher's work.

The QRA analysis process begins with the preparation of a deterministic schedule as the initial input for developing the QRA model. A deterministic project schedule is a project scheduling method that assumes the duration of each activity is known with certainty. In this method, there is no consideration of uncertainty or variability in time estimates. The activities in the deterministic schedule have been determined from the beginning of the project following the project scope. These activities in the deterministic schedule are the objects of the QRA simulation, where the duration of each activity will be reapplied by considering the uncertainty of the duration and the list of risk factors identified in research conducted by (Hermawan et al., 2024). The uncertainty of duration is identified through an intensive interview process through FGD with experts as a data collection technique.

In this FGD, experts were provided with data on the risk factors that had the most significant impact on project schedule performance, as a result of the findings from research by (Hermawan et al., 2024), and deterministic project schedule data. The experts were asked to map the risk factors that had the highest impact as stated in **Table 2** and determine the impact of these risk factors on the activities in the project schedule. After this mapping was done, the experts were then asked to determine the optimistic, most likely, and pessimistic durations for each project activity.

For the activity duration determination, uncertainty estimation was done using a percentage estimation approach based on agreement in the FGD and historical QRA data. The deterministic schedule was prepared and used as the initial schedule to develop the QRA model. All risks were mapped to the impacted activities based on discussions with the experts. The QRA process flow is an important part of QRA implementation as it is the application of principles and frameworks that will determine the results of the QRA. **Figure 2** shows the QRA process flow in this study.

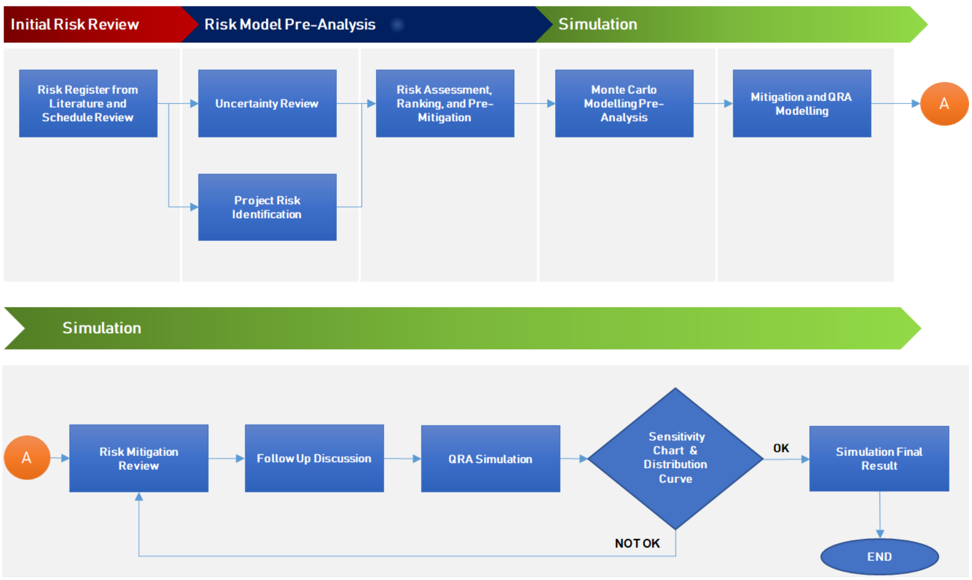


Figure 2. QRA process chart.

Source: Researcher's work.

Table 2. Highest impact risk factors.

Rank	Risk Variable	Type of Risk
1	Financial problems of contractors due to mismanagement	Financial
2	The virus pandemic causing project activities to be disrupted	Health, Safety, Security
3	Material delays due to poor vendor quality and performance	Supply & Logistic
4	Punch list activities that need to be completed before commissioning	Technical
5	Travel restrictions due to the pandemic	Health, Safety, Security
6	Contractor's failure to meet the agreed design	Technical
7	Differences between FEED assumptions and field conditions	Technical
8	Delays in the fabrication stage	Supply & Logistic

Source: Hermawan et al., 2024.
Source: Researcher's work.

The case study for this research is one of the Indonesian ongoing national strategic gas plant megaprojects which located in Java Island. In the Initial Risk Review phase, the project schedule will be used as a basis for developing the QRA. The schedule used is deterministic in Primavera P6 file format. This schedule is a schedule that has been developed by the project planning team. The total number of activities at level 3 of the project schedule is 8210 activities, with 3619 of them being activities that still have remaining duration or activities that have not yet started. A scheduled health check is conducted to ensure that the schedule to be used in the QRA does not have hidden critical paths.

The second process is the Pre-Risk Model Analysis. The approach used in developing the risk model is by analyzing duration uncertainty and risk identification. Information for duration uncertainty is obtained by conducting FGDs, while top risks have been identified in **Table 2**.

The effect of risk on activity duration will affect duration uncertainty in the form of three duration options: optimistic, most likely, and pessimistic. After all information is collected, the next process is QRA simulation using several scenarios to obtain optimal results. Optimization is performed on activities with the largest sensitivity percentage. QRA simulation is conducted using the PRA program.

Table 3. FGD experts' profile.

No.	Description	Experience	Position
1	Expert 1	33 years	Manager Surface Facility
2	Expert 2	21 years	Assistant Manager Procurement Operation
3	Expert 3	20 years	Assistant Manager Commissioning & Start-Up
4	Expert 4	18 years	Assistant Manager Construction
5	Expert 5	20 years	Sr. Analyst Risk Management
6	Expert 6	18 years	Sr. Analyst Formalities & Regulatory
7	Expert 7	15 years	Assistant Manager Instrument & Facility Tie-In Coordinator
8	Expert 8	21 years	Project Control Manager
9	Expert 9	19 years	Sr. Planning Engineer

Source: Researcher's work.

Nine experts from various fields and relevant departments were involved in this Focus Group Discussion (FGD). The profiles of these experts are listed in **Table 3** below.

Modeling was conducted using Primavera P6 software, leveraging the PRA feature. PRA is a software that utilizes Monte Carlo-based cost and schedule analysis to provide risk management throughout the project lifecycle (Oracle Corporation, 2024). The project schedule data used as a case study is the data as of 25 April 2020, with a deterministic target completion date of 21 October 2021. The primary objective of this PRA modeling is to assess and manage project-related risks by identifying risks, assessing risks, analyzing the cumulative impact of risks, developing mitigation strategies, and monitoring and controlling risks.

The Distribution Chart and Tornado Chart are two visual tools used to communicate the results of the Monte Carlo analysis. The Distribution Chart shows the likely distribution of project outcomes based on various simulations. This chart can help to understand the range of possible outcomes and the likelihood of each outcome. The Tornado Chart shows how changes in the value of a particular input variable can affect the project outcome. This chart can help project managers identify the most critical input variables and develop strategies to manage the risks associated with those variables. A deterministic schedule was prepared and used as the initial schedule to develop the QRA model. The referenced schedule was examined using PRA software and several tasks with uncertain durations (open-ended) and incorrect lags were found. Corrections and modifications were made in detail down to a level where the analysis could accurately evaluate the impact of uncertainty and risk of each activity. The schedule logic, logical dependencies, and relationships between activities including their lags remained the same as the original reference schedule. For QRA in this study, the analysis focused on the remaining work.

Activity durations are primarily estimated based on data from previous projects. From one project to another, the actual duration of a task can vary from the shortest to the longest duration. Differences in duration for the same task can be caused by different suppliers or contractors, different productivity levels, different equipment or tools used, different production methods, and other factors. If the actual duration of a task from different projects is plotted on a graph showing duration (as the X-axis) and frequency (as the Y-axis), the duration distribution will show a different shape. This distribution can take the form of a triangular distribution, a normal distribution, a beta curve, and others. This information will determine the duration estimate for a task.

In most projects, a triangular distribution is generally used to estimate task durations. This type of distribution provides a range of durations from the minimum duration (optimistic), the most likely duration, and the maximum duration (pessimistic). This triangular distribution is often skewed to the left. This is because most tasks are completed later than planned. This causes the minimum duration to be closer to the most likely duration than the maximum duration. A visualization of the triangular distribution can be seen in **Figure 3**. In addition, when estimating task durations, the spread of the distribution is also determined by the accuracy of the information available such as the scope of work, specifications, construction methods, suppliers, contractors, databases from previous projects, experience, economic and political situations, market conditions (supply and demand), etc. The availability of this information will determine the spread of the duration distribution. A triangular distribution is used when historical data is insufficient or when using judgmental data.

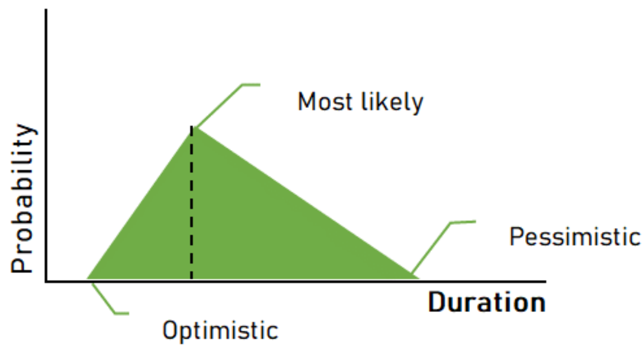


Figure 3. Duration triangular distribution.

Source: Researcher's work.

In the Focused Group Discussion (FGD), experts agreed based on their experience with previous QRA activities in the company, that the following rules in **Table 4** should be applied to assess the duration distribution range in this QRA activity:

Table 4. Estimated duration range.

Duration	Estimated Duration Range
<10 days	70%–130%
<20 days	80%–120%
<40 days	85%–115%
>40 days	90%–110%

Source: Researcher's work.

At the initial stage, the deterministic duration is set as the Most Likely Duration. The duration for specific activities is determined based on available information about the task, previous project records, productivity distribution, and others. In some cases of work items, the duration uncertainty can be modified with a duration range of 90%–125% depending on the agreement of the experts in the FGD. PRA uses Monte Carlo simulation to generate a distribution graph that shows the probability of project completion according to the target date. This simulation considers three scenarios: duration uncertainty, pre-mitigation phase, and post-mitigation phase. The distribution graph displays the frequency and cumulative frequency of each duration interval or date. This graph also shows the confidence levels of P20, P50, and P80, which represent the probability of project completion on or before the remaining duration determined deterministically. The selection of these confidence levels is based on common practices in the Indonesian oil and gas industry.

3. Results and discussion

The analysis of the QRA modeling results will focus on evaluating the completion of the gas plant project, which was deterministically targeted for completion on 21 October 2021. There are two main analyses conducted: (1) Probability distribution of the project acceptance completion date; and (2) Duration sensitivity analysis, conducted using a tornado diagram to identify activities that have a direct impact on the overall project schedule or deviation. The distribution curve for the completion date of each activity will show the probability of each activity being finished by a specific date. An activity with an 80% probability or P80 can be found from 1000 simulation iterations, meaning there is an 80% chance of completing the activity by that date (Bovteev and Mishakova, 2020). The Tornado diagram shows the sensitivity of activities relative to critical activities. Mitigating sensitive activities will have a direct impact on the completion of the project or critical activities.

In this research, the QRA simulation process is divided into two stages: pre-mitigation and post-mitigation, based on the sensitivity analysis results from each previous stage:

a. Pre-mitigation: The analysis is conducted using a deterministic project schedule that has been supplemented with triangular distribution analysis results.
b. Post-mitigation: The mitigation undertaken is by separating the schedule of activities that have the greatest impact on the likelihood of the overall project schedule being delayed.

3.1. Pre-mitigation analysis

This pre-mitigation analysis report presents an assessment of probability distributions, identification of potential risks and uncertainties that may impact project acceptance and other critical achievements, as well as duration sensitivity when risks are not mitigated, and uncertainties are not well addressed for critical activities. Analysis was conducted by performing a Monte Carlo simulation on the project's deterministic schedule using PRA. A total of 1000 iterations were carried out to obtain a probability distribution model and a sensitivity analysis of project activities toward achieving project acceptance.

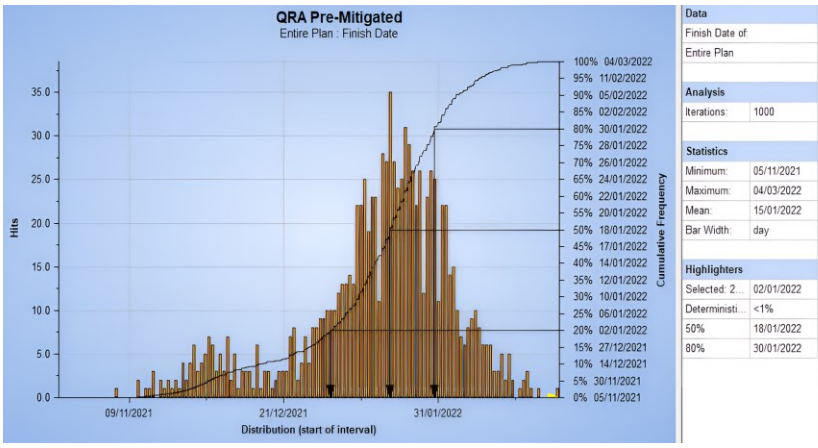


Figure 4. Pre-mitigation probability distribution.

Source: Researcher's work.

As can be seen in **Figure 4**, the probability distribution curve from the pre-mitigation analysis, the project acceptance schedule P80 falls on 30 January 2022, P50 on 18 January 2022, and P20 on January 2. These probability acceptance dates are summarized in **Table 5**. The probability of the deterministic date for project acceptance on 21 October 2021, is very small, below 1%.

Table 5. Pre-mitigation project completion probability.

Probability	Acceptance Date
P20	2 January 2022
P50	18 January 2022
P80	30 January 2022

Source: Researcher's work.

Meanwhile, in the Tornado chart in **Figure 5** for the sensitivity index analysis, and **Figure 6** for the duration sensitivity, it was found that activities related to the fabrication of Acid Gas Incinerator (AGI) equipment were among the top 4 activities with the highest sensitivity to achieving the project acceptance schedule. Meanwhile, in the criticality index analysis, it was found that activities related to production ramp-up occupied the top positions in the list of critical activity indices.

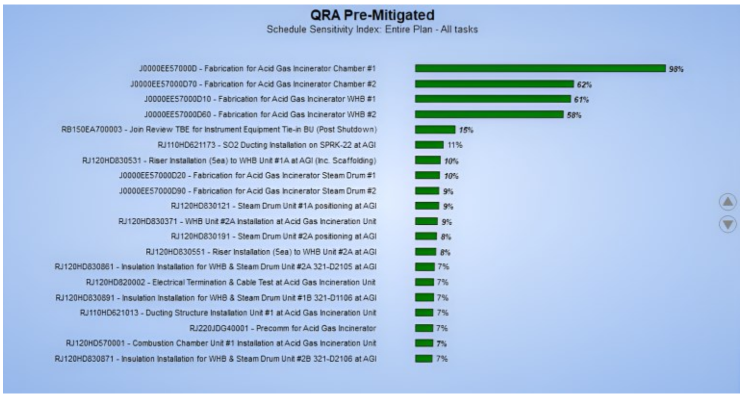


Figure 5. Pre-mitigation schedule sensitivity index.

Source: Researcher's work.

Sensitivity analysis reveals the activities and risks that have the most signifi (Hatmoko and Khasani, 2020) lays. The percentage value in sensitivity analysis indicates the level of influence of an input variable on the simulation results (Hatmoko and Khasani, 2020).

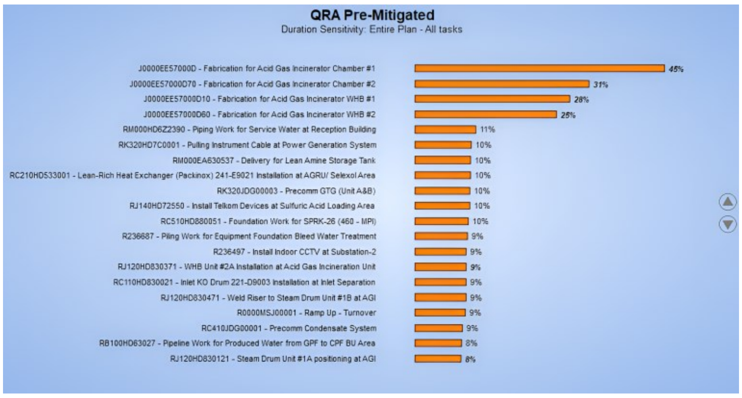


Figure 6. Pre-mitigation duration sensitivity.

Source: Researcher's work.

The higher the percentage, the greater the influence of that input variable on the simulation results. The schedule activity sensitivity index and duration sensitivity show which activities and activity durations have the greatest potential to affect project delays.

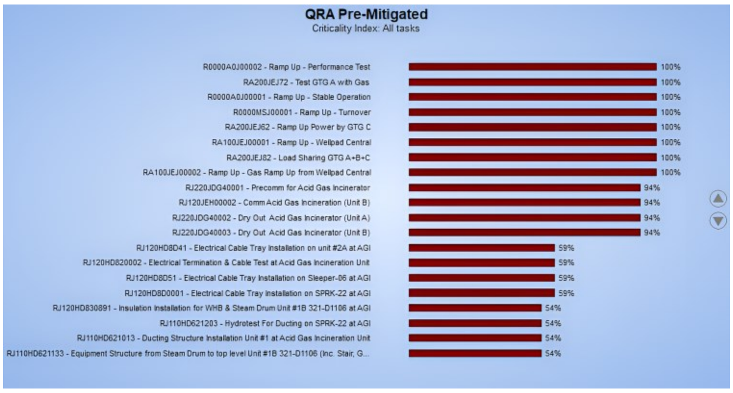


Figure 7. Pre-mitigation criticality index.

Source: Researcher's work.

In **Figure 7**, the criticality index is the percentage of times an activity is part of the critical path in the PDM diagram over 1000 iterations. There are eight activities with a 100% criticality index. This indicates that these activities are always part of the critical path during the simulation. However, the criticality index cannot be used to conclude which activities have the most significant impact on project delays; therefore, sensitivity analysis is used for this purpose.

From the pre-mitigation analysis above, it was found that if the project team decides to wait for the fabrication of AGI, the delay in project acceptance will be quite significant, between 4–5 months compared to the initial plan in the deterministic schedule. Therefore, from the results of this pre-mitigation simulation, the FGD participants agreed to first conduct mitigation by re-sequencing the fabrication activities of AGI, and second, to accelerate the fabrication and delivery of AGI by changing the material delivery method from the previous sea freight to air freight, and then conduct a post-mitigation schedule modeling simulation.

3.2. Post-mitigation analysis

In the tornado chart of the pre-mitigation simulation results, 20 activities were found to have the highest sensitivity index values. In this study, a post-mitigation analysis was conducted on the four activities related to AGI fabrication, which had the highest sensitivity index. The PRA schedule model for production ramp-up without AGI was modified by releasing the logical dependency between the construction and commissioning of AGI from the predecessor activities of production ramp-up and shortening the duration of fabrication and material delivery. Using the same simulation method as the pre-mitigation analysis, the simulation results shown in **Figure 8** were obtained.

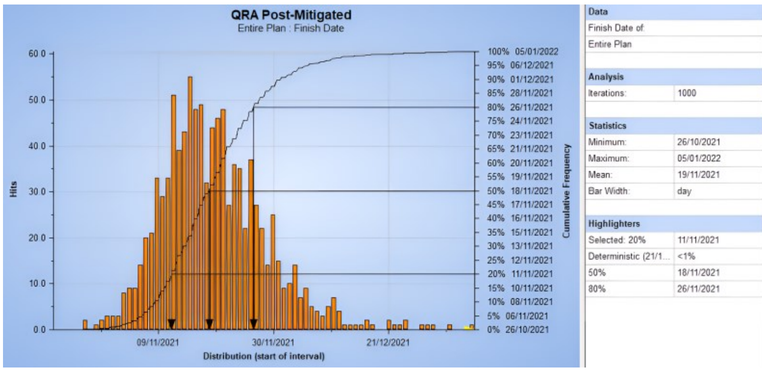


Figure 8. Post-mitigation probability distribution.

Source: Researcher's work.

The QRA analysis report provides an evaluation of the schedule probability for the gas plant project. Using Monte Carlo simulation, the report in **Table 6** demonstrates the positive impact of the mitigation performed by accelerating the project completion by 61 days at P50 and 65 days at P80.

Table 6. Post-mitigation vs pre-mitigation project completion probability.

Probability	Post-mitigation	Pre-mitigation	Acceleration
P20	11 November 2021	2 January 2022	52 days
P50	18 November 2021	18 January 2022	61 days
P80	26 November 2021	30 January 2022	65 days

Source: Researcher's work.

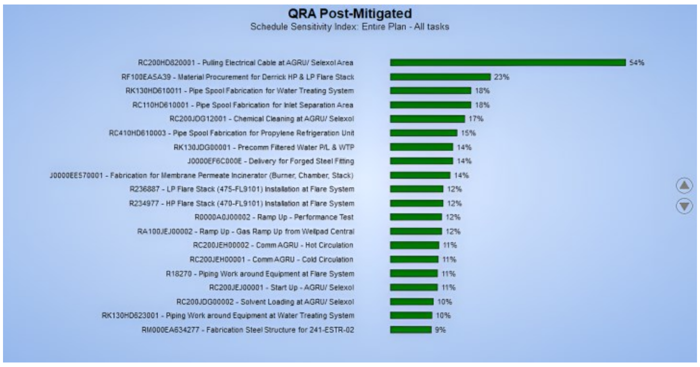


Figure 9. Post-mitigation schedule sensitivity index.

Source: Researcher's work.

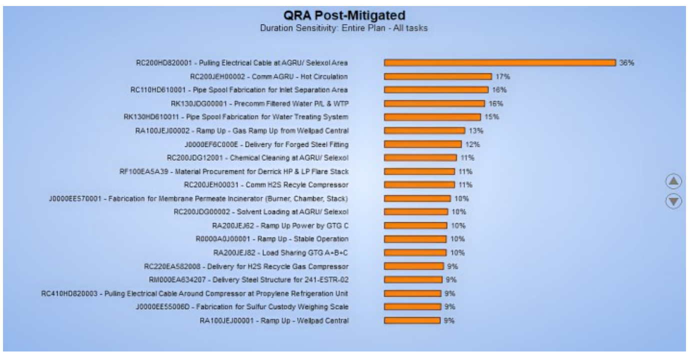


Figure 10. Post-mitigation duration sensitivity.

Source: Researcher's work.

From **Figures 9** (sensitivity index) and **10** (duration sensitivity) of the post-mitigation analyses, it was found that the activity with the highest sensitivity to project delay has changed to "Pulling Electrical Cable at AGRU Selexol Area". This indicates that the potential project delay due to the late fabrication of AGI has been mitigated effectively.

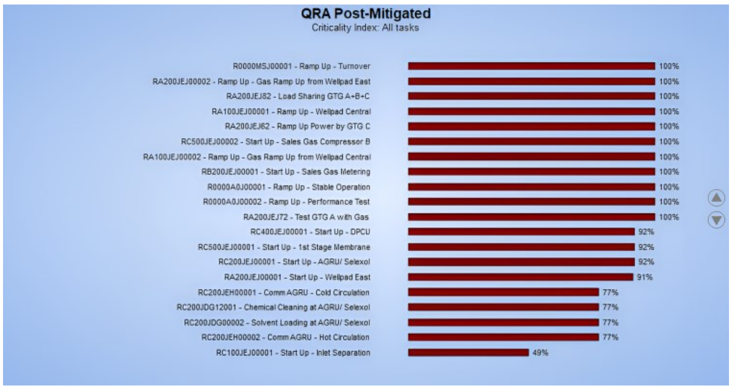
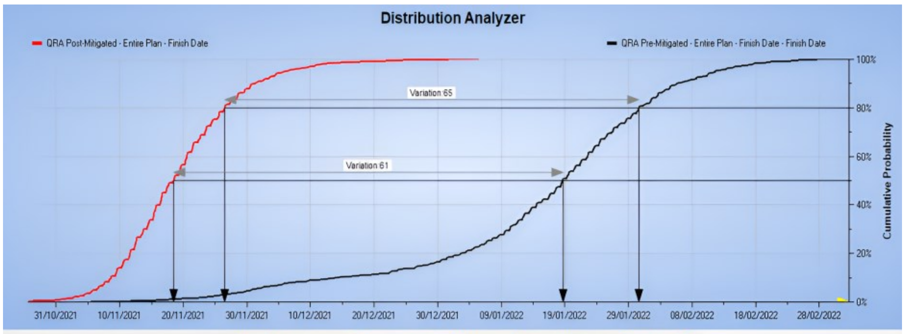


Figure 11. Post-mitigation criticality index.

Source: Researcher's work.

If we look at **Figure 11**, we can see that the tasks related to starting full-scale production are the most important ones. This means that these tasks almost always affect how long the entire project takes.



	Show	Deterministic Value	Deterministic probability	Minimum	Maximum	Mean	Selected: 50%
QRA Post-Mitigated - Entire Plan - Finish Date	☑	21/10/2021	<1%	26/10/2021	05/01/2022	19/11/2021	18/11/2021
QRA Pre-Mitigated - Entire Plan - Finish Date - Finish Date	☑	21/10/2021	<1%	05/11/2021	04/03/2022	15/01/2022	18/01/2022

Figure 12. Pre-mitigation vs post-mitigation distribution analysis.

Source: Researcher's work.

Figure 12 compares the project schedule before and after we made the changes. The graph shows that the changes we made helped to speed up the project, especially when it came to finishing the project and getting project acceptance. To obtain simulation results that are closer to the deterministic schedule, additional mitigation and modeling simulations are needed, especially for activities that show high sensitivity in the tornado chart.

4. Conclusion

Risk modeling most significantly influences the gas plant project and its relationship to the project schedule duration using the PRA program.

a. The first simulation was conducted on the pre-mitigated project schedule, resulting in a project completion date shift of 4–5 months compared to the initial deterministic project schedule, depending on the chosen probability level. This proves that when risk factors are applied to the project schedule, the project completion date is very likely to shift depending on the risk level and the number of risks included in the simulation modeling. Mitigation was conducted on the activity with the highest sensitivity in the sensitivity index graph, that is the fabrication of the Acid Gas Incinerator, by changing the material delivery duration through a change in the delivery method from sea to air.
b. Re-modelling was conducted by incorporating the risk mitigation results into the schedule, and it was found that the simulated project completion schedule after mitigation experienced an acceleration of 61–65 days compared to the results of the initial simulation. This proves that mitigation conducted on activities with a high sensitivity index has a significant impact on improving schedule performance.

This research contributes to several important aspects of project management, particularly in gas plant construction projects. With better risk identification, the project team can prepare appropriate mitigation and anticipation strategies to minimize the negative impact of these risks. The quantitative risk analysis method used in this research enables the project team to estimate the probability and impact of each risk more accurately. This information can be used to develop a more realistic project schedule and consider potential delays that may occur. This can help the project team to complete the project on time. By proactively managing risks, the project team can avoid or minimize additional costs that may arise from occurring risks. For example, by identifying the risk of delayed material procurement and taking anticipatory measures, the project can avoid late delivery penalties and optimize storage costs. In general, the above will improve overall project performance. Projects with good performance will yield more optimal results, in terms of time, cost, and quality. This research contributes to the oil and gas and non-oil and gas project industries by introducing models, and methods for managing project risks more effectively. The findings of this research can be adopted by companies, especially those in the oil and gas and construction industries in general, to improve the success of their projects.

The inclusion of a variety of parameters and variables in project management research can indeed be complex. This is because many factors in project management are interconnected and influence each other. External factors and unforeseen events can introduce significant variability. Gas plant projects are inherently complex due to their size, technological requirements, and regulatory compliance. Despite the complexity, comprehensive research that considers a wide range of parameters and variables can significantly contribute to the success of a gas plant construction project, particularly in terms of managing schedule risk. Project managers can gain a deeper understanding of potential risks, make informed decisions, and develop effective risk management strategies to increase the likelihood of project success.

Although this research has made substantial contributions to theory and practice, it has inherent limits that require additional research.

a. Simulation of risks and project schedules should be conducted before project execution so that mitigation can be carried out from the beginning of the project.

b. Research on the combination of QRA on the performance of the schedule and cost performance of gas plants or similar projects is needed, considering that this study did not measure the impact of risk mitigation on the schedule and its effect on project costs.
c. Comparison with the results of QRA methods using other applications such as @RISK, RiskAMP, CrystalBall, and others.
d. Further simulation of residual risks that have not been mitigated needs to be conducted to determine the extent to which risk treatment can be done to improve project completion estimates.
e. The application of QRA in oil and gas projects needs to be expanded to offshore, pipeline, drilling, and downstream refinery projects.

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