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Overall Risk: An Effective Approach in Project Management and Decision Making

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Abstract

Risks constantly add complexity to the decision-making process in Oil & Gas industry. Risk register and risk matrices are common tools used to manage risks, but a list of risks cannot answer sponsors and stakeholders "How risky" question, especially those related to highly technical subjects. However, estimating the overall risk can address these concerns. Project Management Institute define overall risk as "the effect of uncertainty on the project as a whole, more than the sum of individual risks within a project…". The objective of this paper is to provide guidelines to estimate overall risk to make risk-informed decisions by modeling the effect of uncertainty in the achievement of objectives, providing an analysis that puts project stakeholders and sponsors in context, even in high complexity projects.

Introduction

When reporting risk from multi-disciplinary teams may be difficult to communicate them to sponsors and stakeholders because they do not always have a technical background of all the disciplines. Also, explicit manual enumeration of all the risks included in the risk register could be impractical. A solution to this situation is to estimate the overall risk of the project, which can be more than the sum of individual risks within a project (PMBOK, 2017).

Probabilistic Risk Assessments (PRA) allows one to estimate the overall risk. PRA provides risk managers with information about the uncertainties in the data, models, assumptions, and results, providing decision-makers with a better understanding of the impact of uncertainties on the project. PRA also can be used to support risk management by using sensitivity and uncertainty analyses to assess potential decision alternatives. (United States Environmental Protection Agency, EPA, 2014). The U.S. Environmental Protection Agency (EPA), U.S. Nuclear Regulatory Commission (USNRC) and the National Aeronautics and Space Administration (NASA) apply PRA models to better understand and effectively manage risk and as a tool to explore how some decisions will affect risk before the project is committed to that path.

Overall risk and PRA allow to:

- Make risk-based decisions.

- Make a hierarchical analysis of the most important variables on the project.
- Evaluate the impact of potential program changes before they are executed.
- Communicate stakeholders and sponsor expectations into quantifiable objectives.
- Understand which uncertainties strongly affect the decision outcome and if they are potentially reducible through research or any other way.

This paper presents a methodology inspired in NASA PRA tools that can be apply on many aspects of the O&G business such as finance, operations, decision making, health and safety, environmental issues, engineering, etc.

Related Literature

PRA is being applied in a wide range of purposes in numerous industries. Flowing will be present related literature to PRA in other industries and O&G. Appendix A contains some definitions that support this paper.

PRA in Other Industries

Kapplan et al. (2016) explained in an editorial that PRA was developed by the nuclear power industry and initially published in mid-1975. NASA adopted and embraced PRA for the Space Shuttle and International Space Station programs to strengthen its safety and mission assurance capabilities after the Space Shuttle Columbia was lost on re-entry in February 2003. At NASA, qualitative approaches such as fault trees, failure modes and effects analyses, hazard assessments, etc., are augmented by a quantitative risk-assessment technique called PRA to uncover and mitigate low-probability sequences of events that can lead to high-consequence outcomes.

The USNRC requires a facility-specific PRA for every nuclear power plant in the United States. The USNRC uses PRA to estimate risk by computing real numbers to determine what can go wrong, how likely is it, and what are its consequences. EPA incorporate PRA into the Agency's decision-making process in response to recommendations from numerous advisory bodies, including the Science Advisory Board, the National Academy of Sciences and USNRC. PRA began playing an increasingly important role on this Agency risk assessments following the 1997 release of EPA's Policy for Use of Probabilistic Analysis in Risk Assessment in the United States.

PRA in O&G

Safety and quality are applications for PRA in O&G. Mayfield et al. (2019) used NASA risk management process and Systems Engineering handbook to examine the O&G company's global projects risk management procedure, finding that NASA systems engineering processes could benefit the O&G industry by streamlining their risk management procedures, providing a 61% reduction of unnecessary requirements.

Keilty et al. (1996) applied Quantitative Risk Assessment (QRA), a probabilistic tool, to address the question in the casing design process: "How often will a failure occur?". The purpose of probabilistic design was to replace over- or under-engineering with consistent design that is fit-for-purpose.

Codling et al. (2013) described techniques for directly extracting the operation information and provide an approach to forecasting using probabilistic methods, user friendly to review the input data for planned operations in the Monte Carlo model.

Other papers assessed cost and time risk management, applying Monte Carlo simulations and sensitivity analysis. Mattioli et al. (2009) developed a simulation model of drilling activities to estimate the impact of generic and specific risk and uncertainty on the overall duration and cost of the project. Mattioli et al. used triangular distributions to build the model, however, due to the lack of information about the technology used to drill the well, some distributions were derived using expert judgment. Saibi (2011) evaluated time and cost of wells, in an Argelia field, determining distribution functions for the projected well time and cost.

A software carried out multiple trials through sampling values from triangular probability assigned to each operation, and then recalculates the time and cost with respect to the design parameters. Kitchel et al. (1997) combined a drilling-cost spreadsheet with a forecasting and risk analysis program to predict the range of both time and cost necessary to drill a well. A tornado chart was generated to enable the cost estimator to identify easily which components or assumptions of contribute the most to the uncertainty in the cost estimate. Akins et al. (2005) built a time and cost model to be used throughout the well construction life cycle, from project conception through operations and as a tool for project review, using this model as a tool to enhance senior management and asset team understanding of possible project time and cost outcomes.

Hariharan et al. (2006) presented an approach and a tool for estimation of drilling time and cost used to evaluate the effect and impact of novel technologies in comparison to conventional methods.

Methodology

The methodology presented in this paper is inspired in NASA Risk Management (RM) process, that is used to inform systems engineering decisions through better use of risk and uncertainty information, in selecting alternatives and establishing baseline performance requirements. And manage risks over the course of the project life cycle to assure that these requirements are met. Following the steps to apply the methodology:

1. Build a model diagram that represents the process.
2. Assign values and probability distribution to each variable in the model.
3. Estimate the overall risk applying Monte Carlo simulation.
4. Perform sensitivity analysis.
5. Communicate the results.

Build a model diagram

The first step is to build a model that represents the process, considering all the information available, including internals and externals factors. The model must include not just planned operations sequence but also identified undesirable events that may occurred.

The model is represented in a flow chart that allow to the project team to visualize the workflow and understand the logic behind it. The complexity of the model should increase as the project is progressing. If more data or detail of one or more variables is known, the model should be immediately updated. These iterations should be performed until the operation is executed. Fig 1 shows a simple example to illustrate how the flowchart is incrementing complexity as the planning phase is progressing. In this example, tool failure and hole stability are pivotal events, because they are binary variables used to specify if a given event either occurs or not.

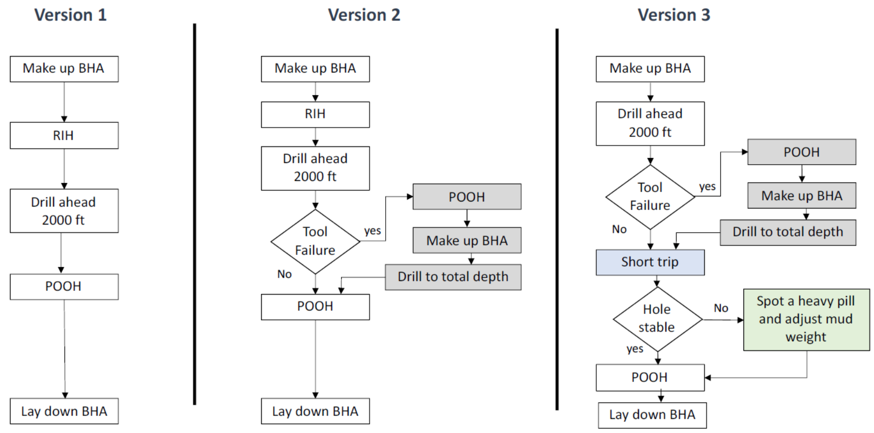


Figure 1—Illustration of the evolution of the model diagram.

It is recommended to bring as much detail as possible to the flow chart to be able to evaluate realistic scenarios. Even external factors, such as bad weather or inflation can be incorporated into a given project model.

Assign values and probability distribution to each variable in the model

Based on what is currently known, a probabilistic distribution, probability or value is assigned to each variable defined in the model to turn it into a mathematical model. On every iteration of the model diagram, values must be assigned to the new parameters or variables, and the rest of variables updated or validated. The ideal situation is to have enough representative records of each variable to fit a continuous distribution, however, domain expert judgment (DEJ) may be required to estimate the frequency or probability of an event when there is not enough data or the data available may not be representative.

There are some distributions frequently used when there is little or no data available for a given variable. Uniform distribution is used when only two parameters are set, minimum and maximum values and the outcome is expected to lay between those boundaries, for example, install the logging unit may take between 60 to 90 minutes, any time in this range is equally likely to happen. If in addition to the minimum and maximum there is a most likely estimate, triangular and beta-PERT distributions may be selected to favors the most likely value. Normally, a probability of occurrence is assigned to a pivotal event instead of a continuous distribution. Fig 2 illustrate the difference between a pivotal event and a variable. In this example, "Tool Failure" is considered as a pivotal event with a probability of occurrence of 20%, while the other variables respond to a continuous distribution function, as it is the case of "Drill Ahead 2,000 feet", that is described by a normal distribution.

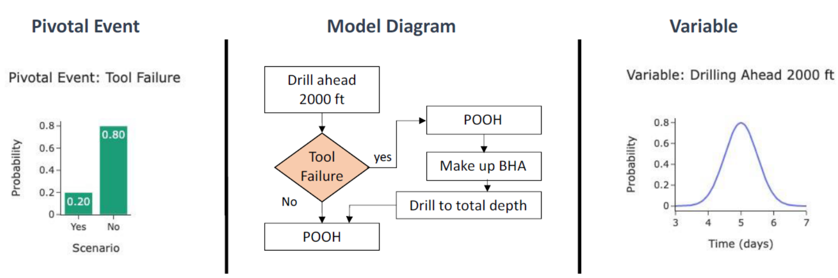


Figure 2—Illustration of Pivotal Events and Variables.

Estimating the Overall Risk Applying Monte Carlo Simulation

The Models can be analyzed through computer-based algorithms based on input that has been carefully formulated by engineers. The variables are iterated several times and randomly sampled from a probability distribution to simulate the process outcomes and generate probability density functions. Overall risk is defined by the percentage of outcome that do not meet the objective(s), in order words, if 600 outcomes of 1,000 iterations met the objective, the overall risk would be 40%.

There are spreadsheet-based applications that can be added to Excel or other spreadsheet software to run Monte Carlos simulations, but some companies have developed their own fit-per-purpose tools. In this paper, open sources libraries for Python (programming language) were used to create the models and visualizations. NumPy was used to generate the distributions, and Matplotlib and Plotly were used to create the plots. These libraries allow one to build complex models costlessly while providing high quality.

Perform Sensitivy Analysis

Sensitivity analysis is performed considering all the iterations of the model, to understand the results and estimate the importance and effect of every variable over the objective(s). Tornado plots are frequently used to show how sensitive the objective is to each variable. This plot ranks the variables top down in order of their impact on the objective, in other words, at the top will be the variable that add more variance to the model outcome distribution.

The spreadsheet-based application that can run Monte Carlos simulation, also provide sensitivity analysis and tornado plots. However, in this paper others open-source libraries were used to perform the sensitivity analysis. Machine Leaning Algorithm XGboost was used to build a model trained with the simulation's parameters and outcomes. SHAP, SHapley Additive exPlanations, was used to reverse-engineer the output of XGboost model. SHAP quantify the contribution that each variable brings to model outcome.

Communicate the results

The results may be presented graphically or in a tabular data format. The modeling assumptions must be informed as well as insights of the results interpretation and the overall degree of uncertainty about the results. Decision makers must be able to have an understanding of which sources of uncertainty are critical to those results and which are not.

Box plots, probability density functions (pdfs), cumulative distribution functions and histograms are visualization tools for displaying the model uncertainty. Flow charts representing the model can inform the analysis's logic.

PRA Applications in O&G

PRA have multiples applications and can be used to manage and informed uncertainty in forecast, selecting an alternative, physical system performance, time, cots, etc. Following some examples will be presented to illustrate how PRA can help to improve the decision-making process.

Select an Alternative

When alternatives are evaluated applying PRA to make risk-informed decision-making, the impacts of uncertainties must be assessed. Also, managers may want to know how uncertainties could support a different decision alternative or provide further support for the selected decision.

In figure 3, the pdfs show the distribution of two alternatives (A and B). In this case there is a performance constrain (as it is defined by NASA) of 127 days and all possible outcomes that fall over that value define the overall risk. In this example it is also considered a 10% contingency to set the target or objective. The matrixes on the right side of figure 3, also show cost so that time and cost can be evaluated in a single analysis. This analysis can also be done considering two or more alternatives with two or more variables, such as well integrity, environmental risk, etc.

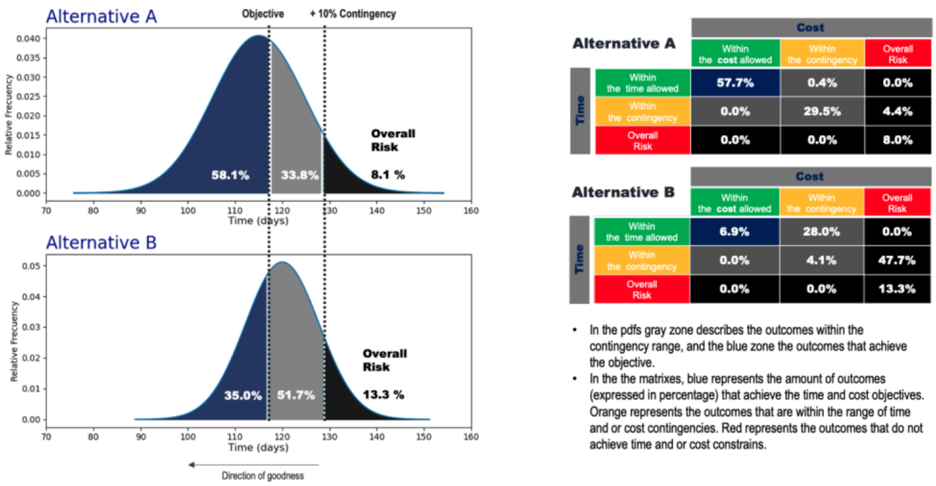


Figure 3—Risk informed decisions by modeling the effect of uncertainty in alternatives.

Objective Definition

To support resource allocation accounting for risk, uncertainty need to be addressed. Building a mathematical model of the process allows to set the goals based on the risk tolerance of the organization or decision makers, putting stake holders and sponsors requirements in context. Also allows to visually understand the magnitude of the opportunities. The project may be complex with hundreds of variables, but the decision makers can evaluate the possible outcomes based on the model considerations, having a good sense of the project risk even if do not have technical knowledge of all disciplines involved.

Figure 4 shows an example of setting goals based on uncertainty. The pdf describes the uncertainty of the project. Project has a 19.8 million USD constrain; therefore, black zone represents both risk tolerance and the overall risk (20%), however the target is set considering 10% contingency. Percentile 0.5% is 14.4 million USD, therefore, even a 38% probability of achieving the target is estimated, the organization still has more than 3.5 million USD opportunity if optimization strategies are put in place. NASA defines the amount with contingency (19.8 million USD) as performance requirement. As previously mentioned, the model must be updated as more information is available, even when the project is running, and if the uncertainty is reduced the overall risk is expected to be decreased, even if the cost constrain is the same.

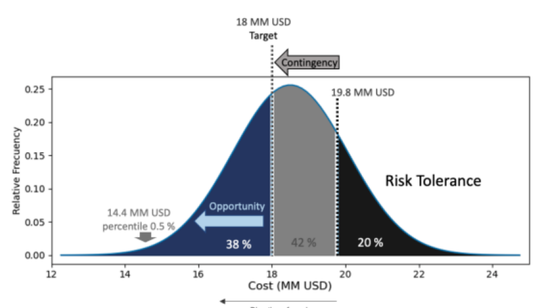
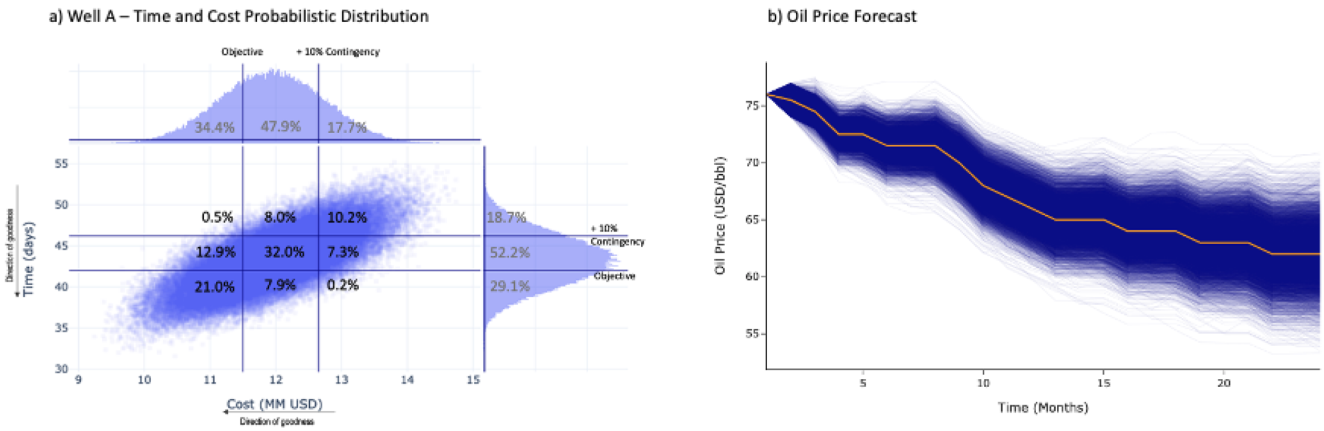


Figure 4—Illustration of the concepts for objective definition.

Project Economics

PRA can be applied to estimate the uncertainty in key performance indicators (KPI). Economics KPI are very important and normally set and followed up by decision makers. Throughout PRA the uncertainty of the KPI can be estimated to understand its context.

In the next example, the uncertainty of the net present value (NPV) of a well is estimated in two years' time horizon. Figure 5a, shows estimated well time and cost distributions. Figure 5b, shows the estimate oil price forecast and random oil forecasts based on the estimate. Time and cost values were randomly sampled from its corresponding distributions. A 2-year oil price forecast was sampled from the 10,000 shown in figure 5b. Figure 6a shows a histogram with the NPV estimated distribution. Notice that the NPV is positive in all the outcomes where the cost objective was achieved. The Sensitivity analysis shown in Figure 6b indicates that the initial production is the variable that contribute the most to the uncertainty. The highest initial production increased NPV by up to 10 million USD. Well cost is the second variable that impacts NPV uncertainty the most. For the highest well cost, the NPV can decreases in 2.5 million USD, while for the lowest cost, the NPV can increase in the same amount.



Vertical lines indicate the cost objective and 10% contingency, while horizontal lines indicate the time objective and contingency. In the center a scatter plot shows outcomes for the 200,000 iterations. The percentages in indicates how many outcomes are within the line boundaries.

The estimate oil price forecast is shown in orange line, and the thin blue line (with 95% opacity) represent the 10,000 random oil forecasts based on the estimate.

Figure 5—Estimated well time and cost, and oil price forecast.

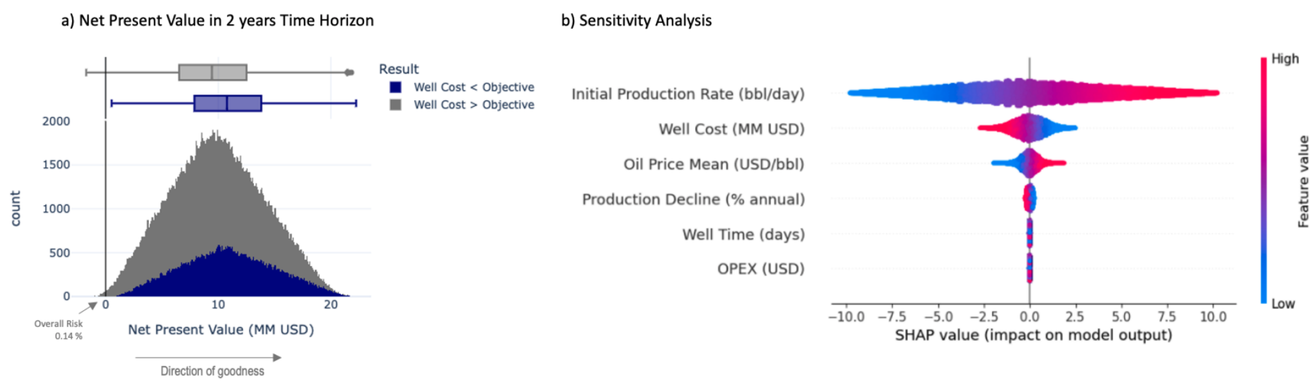


Figure shows the results of the 200,000 iterations. The histogram shows the NPV distribution, indicating in a blue zone the outcomes where the cost objective was achieved. In the top, two box-plots the distribution of the outcomes that met the cost objective and those that did not. Only 276 outcomes show VPN less than zero, which represents an overall risk of 0.14%.

Figure shows a sensitivity analysis derived from a machine learning algorithm (XGBoost) trained with the 200,000 records. The plot represents one dot for each iteration. Blue dots are for the lower values of each variable (on the "y" axis) and red the highest, the color map scale is display at the right side of the plot. "x" values represent the deviation from the mean of the NPV, to the right NPV increases and to the left (negative) NPV decrease from the mean value.

Analysis Considerations:
A 5% discount rate and 40% tax are considered constant. Initial oil production variable is described by a triangular distribution with minimum of 450 bbl/day, average of 800 bbl/day and maximum of 1200 bbl/day. Production annual declination is described by a uniform distribution with a minimum of 2% and maximum of 4%. Operating expenses (OPEX) are described by a triangular distribution with a minimum of 10 USD/bbl, average of 12 USD/bbl and maximum of 14 USD/bbl. Well time and cost are randomly selected from model presented in figure 4a, as well as the oil price forecast (figure 4b).

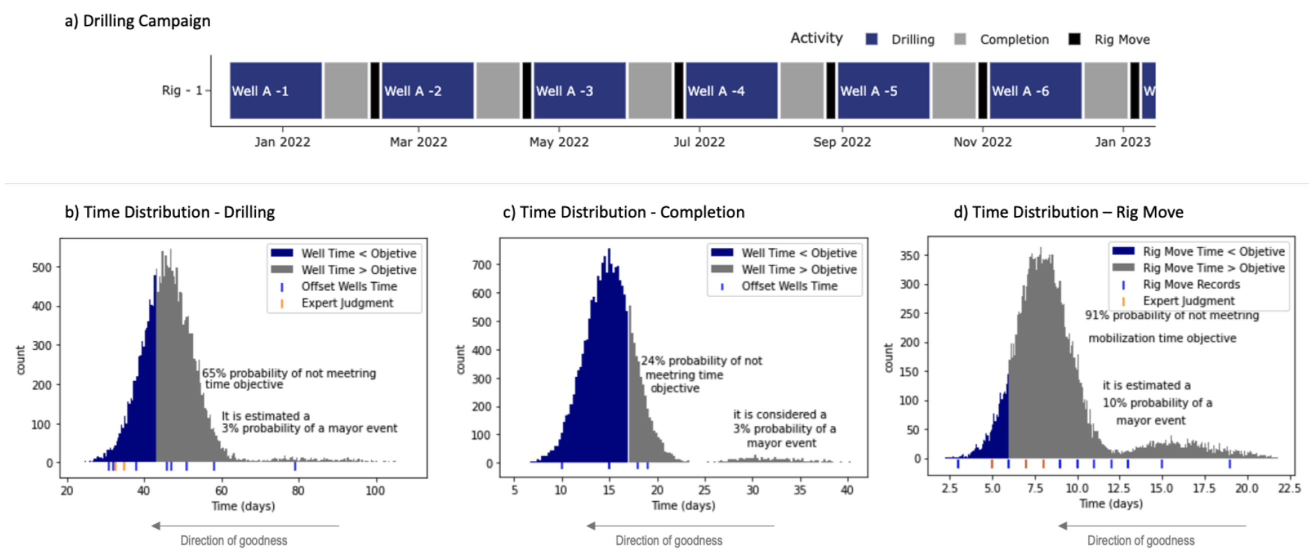
Figure 6—NPV distribution and its sensitivity analysis.

The example explained above is relatively simple for illustration purposes, but the model can consider many other variables to measure its impact on the overall risk. It is possible to estimate how much the NPV is affected by tools reliability, slip-to-slip connections, weather window, exchange rate, rate of penetration, among others.

Project Portfolio

Project portfolios can also be modeled. By linking different project models and evaluating the effect of each project or a specific variable, one can determine how they impact the portfolio's performance. It is possible to measure how today's decision may impact the future. Also, alternative portfolio can be evaluated on paper as new information is collected, to have a sense of what if something changes.

In the following example, a well drilling portfolio is analyzed to estimate the uncertainty of achieving the net oil production for a given time period. For simplicity, in this model only time will be assigned with a distribution, leaving constant the initial production rate and production decline. Figure 7a shows the portfolio schedule. Five well that are expected to produce oil in year 2022. Deterministically, it is expected to have a 2.42 million oil barrels until December 31st, 2022. Figure 7b, 7c and 7d show the estimated time distribution for drilling, completion and rig move activities respectively. In this case contingency is not indicated. Figure 8a shows the distribution of net oil production accumulate to December 31st, 2022, based on the considerations already described, where 71% of outcomes did not achieve the objective. Figure 8b, shows the corresponding sensitivity analysis where drilling time contribute the most to the overall risk. When the mean time for drilling activity on the year has its highest value, the net production can fall in more than 600,000 bbl. Completion and rig moves impact overall risk similarly. Although the relative low completion risk, may contribute positively the target uncertainty.



The blue zone on the pdfs represents the outcomes that achieve the objective and the gray zone the overall risk. In the bottom of the three pdfs there are symbols indicating the actual records of offset wells in blue and expert judgment in orange, those value were used to validate the distributions. Pivoting events were considering on the three-time distribution, with different probability of occurrence and impact, as per interpretation of the offset data and expert judgment.

Figure 7—Time distribution and projects schedule for a portfolio analysis.

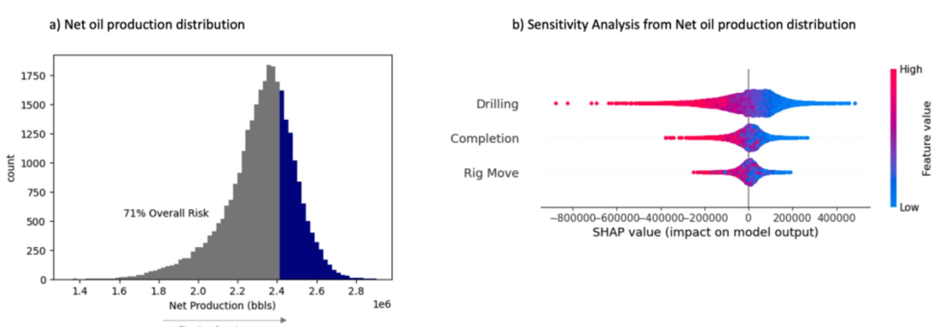


Figure 8—Net oil production distribution and its sensitivity analysis.

Engineering

Most the materials and physical system are built with tolerances and recommended operation ranges. When those specifications are available, describing its probability distribution, it is possible to apply PRA to estimate the probability of failure and understand the importance of the variables involved.

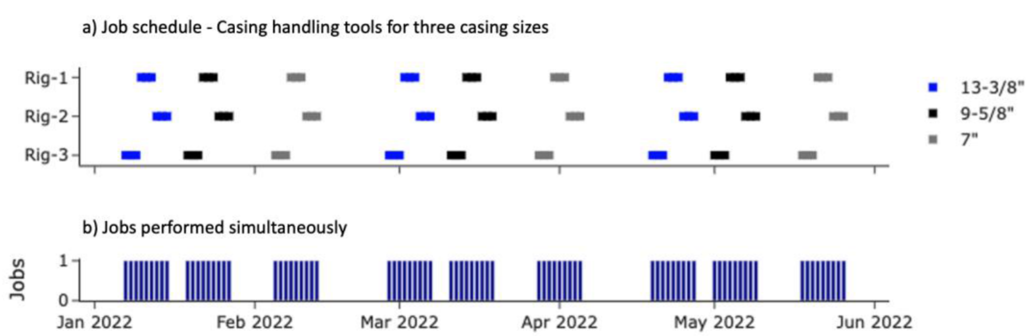
As mentions previously, Keilty et al. (1996) applied QRA, to address this question in the casing design process: "How often will a failure occur?". The purpose of probabilistic design was to replace over or under engineering with consistent design that is fit-for-purpose and to seeking a better understanding of the factors governing their casing designs.

NASA broadly applies PRA in engineering, as its logical, systematic, and comprehensive approach, has proven capable of uncovering design and operational weaknesses that had escaped when apply other conventional techniques. In the O&G business, NASA and Anadarko performed a PRA of generic 20K blow out preventers. The scope included the hardware systems, operations and human interactions associated with a typical subsea BOP.

Resource management

Labor, materials, services, equipment need to be provided on time. PRA allows to analyze the schedule of these resources to be able to answers, what is the probability to perform a job a given date? what is the probability of require two stimulation vessels if only one is available? etc.

In the following example, casing handling tools are planned to be used on three rigs. Each job is expected to last three days. Figure 9a shows the jobs schedule for three different tool sizes. It can be notice in figure 9b, that simultaneous jobs are not expected. The results are shown in fig 10a and 10b. Figure 10a shows different probability curves (1%, 10%, 20%, and 30%). As it can be seen, it is estimated 1% (percentile .99) probability of requiring three simultaneous crews up to March and at the beginning of May, and 30% probability of requiring only one crew from February on, in other words, in 70% no more than one crew is required. Figure 10b shows an alternative graphical representation of the results.



Uniform distributions were assigned to the time between jobs and the start of the first job on each rig, January 2022. The model was iterated 20,000 times.

Figure 9—Job schedule for casing handling tools.

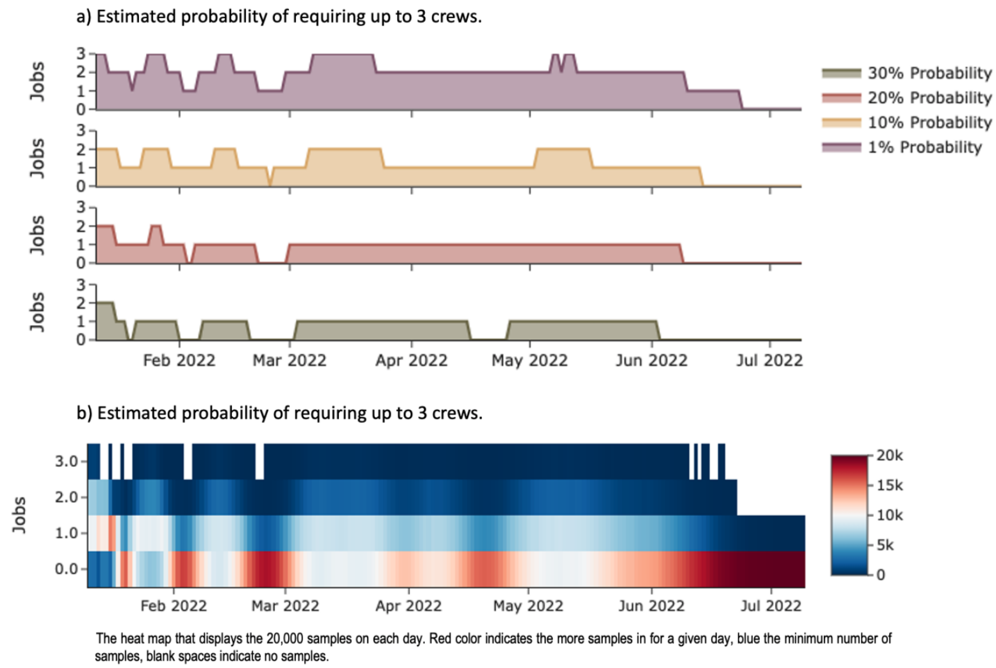


Figure 10—Probabilistic assessment to estimate probability of requiring up to three crews.

Other Applications

As it has been shown, PRA can be applied to many different processes, of different areas of knowledge. In safety, Bureau of Safety and Environmental Enforcement (BSEE) and NASA have developed a draft guide for the use of PRA in the offshore oil and gas industry. In 2016, BSEE and NASA entered into an interagency agreement to, among other joint goals, evaluate the use of PRA in the offshore oil and gas industry.

Deloitte announced a strategic alliance with NASA to provide operational risk-management services to companies, aimed at companies looking to minimize the risk of catastrophic failures – the kinds of dramatic mishaps that, while highly unlikely, can occur in remote and harsh environments, in activities such as deep-water drilling, undersea production and pipeline, among others.

Considerations When Applying PRA

It has been demonstrated how versatile PRA application can be used in O&G business. It can be applied in any process that could be represented in a mathematical model. There are no limitations, and the complexity of the model will dictate the deep of the analysis. However, when estimating overall risk trough PRA, attention must be paid to the uncertainty of the model itself and the hardware capabilities to run the simulations.

The design of the model must be carefully developed and validated before it is used for decision making. EPA (2013) awares on its documentation that uncertainty can be present in the input variables, model, or in the scenarios. Model uncertainty refers to gaps in the scientific knowledge or theory that is required to make accurate predictions, while scenario uncertainty refers to errors, typically of omission, resulting from incorrect or incomplete specification of the risk scenario to be evaluated. NASA also points out that if there is epistemic uncertainty associated with the parametric inputs to a model, then there is epistemic uncertainty associated with the output of the model, as well. The quality of information will ultimately dictate the quality and accuracy of the results.

When generating samples from probability distribution, it must be considered that samples are more likely to be drawn in the areas of distribution where the probability of occurrence is higher. In the case of a triangular distribution, that is the mean value. Therefore, low probability areas of the distribution such as minimum and maximum values, may not be represented adequately in the samples. To mitigate this, a relatively high number of iterations is required to obtain reliable estimates of the output function. Especially when complex multivariable models are built, because it is necessary to interact minimum and maximum of different variables. If each of those minimum and maximum are just generated once, it will not be possible to evaluate all possible outcomes. Hence, when building complex models with hundreds of variables, it is recommended to consider powerful hardware capabilities to compute the most scenarios possibles in reasonable time.

Conclusion

Estimating the overall risk makes possible for the project sponsor and/or stakeholders to make an informed decision. Without a good risk model, relatively unimportant issues may receive too much attention, and relatively important issues may go unidentified.

An individual risk can impact a certain aspect of a project, but unacceptable overall risk level can end the project.

In project management, overall risk is constantly changing from the planning phase to the end of the project. Models must be updated as new information is collected or new variables that may impact the project are identified.

The quality of the model will drive the quality of the decisions. Even when sophisticated tools such as PRA are available, the organizations will rely on project teams technical skills, knowledge, and commitment to deliver the best analysis possible with the information available.

References

1. Akins, W.M., Abell, M.P., and E.M. Diggins. "Enhancing Drilling Risk & Performance Management Through the Use of Probabilistic Time & Cost Estimating." Paper presented at the SPE/IADC Drilling Conference, Amsterdam, Netherlands, February 2005. doi: https://doi.org/10.2118/92340-MS
2. Codling, J., and J. Leatherby. "Probabilistic Well Time Estimation Using Operations Reporting Data." Paper presented at the SPE Digital Energy Conference, The Woodlands, Texas, USA, March 2013. SPE-163687-MS. doi: https://doi.org/10.2118/163687-MS
3. Hariharan, Peringandoor Raman, Robert Arnold, Judge, and Dat Manh Nguyen. "The Use of Probabilistic Analysis for Estimation of Drilling Time and Costs When Evaluating Economic Benefits of New Technologies." Paper presented at the IADC/SPE Drilling Conference, Miami, Florida, USA, February 2006. SPE-98695-MS. doi: https://doi.org/10.2118/98695-MS
4. Kaplan, David. "Guest Editorial: Risk Management at NASA and Its Applicability to the Oil and Gas Industry." *J Pet Technol* **68** (2016): 14–15. SPE-1016-0014-JPT. doi: https://doi.org/10.2118/1016-0014-JPT
5. Keilty, I.D., and H. Rabia. "Applying Quantitative Risk Assessment to Casing Design." Paper presented at the IADC/SPE Drilling Conference, New Orleans, Louisiana, March 1996. SPE-35038-MS. doi: https://doi.org/10.2118/35038-MS
6. Kitchel, Bruce G., Moore, Steven O., Banks, William H., and Brett M. Borland. "Probabilistic Drilling Cost Estimating." *SPE Comp App* **9** (1997): 121–125. SPE-35990-PA. doi: https://doi.org/10.2118/35990-PA
7. Mattioli, C., Calderoni, A., Gagliano, L., Mattioli, L., Michelez, J., and F. Zausa. "Discrete Event Simulation For The Risk Analysis Of Drilling Projects." Paper presented at the Offshore Mediterranean Conference and Exhibition, Ravenna, Italy, March 2009. OMC-2009-057. https://admin.onepetro.org/OMCONF/proceedings-abstract/OMC09/All-OMC09/OMC-2009-057/1081

8. Mayfield, James Allen. "Process Improvement Based on a Gap Assessment of NASA and O&G Risk Management Processes." Paper presented at the Offshore Technology Conference, Houston, Texas, May 2019. OTC-29510-MS. doi: https://doi.org/10.4043/29510-MS
9. National Aeronautics and Space Administration, "Probabilistic Risk Assessment Procedures Guide for NASA Managers and Practitioners". NASA/SP-2011-3421. Second Edition. December 2011.
10. Project Management Institute, "A Guide To The Project Management Body Of Knowledge (PMBOK Guides)", Sixth Edition. *Newtown Square*, PA: Project Management Institute, 2017.
11. Saibi, M. "Risk Based Approach For Well Planning Applied To Set Drilling Performance Targets." Paper presented at the Offshore Mediterranean Conference and Exhibition, Ravenna, Italy, March 2011. OMC-2011-095. https://admin.onepetro.org/OMCONF/proceedings-abstract/OMC11/All-OMC11/OMC-2011-095/1223
12. U.S. Environmental Protection Agency, "Probabilistic Risk Assessment to Inform Decision Making: Frequently Asked Questions". EPA/100/R-14/003. July, 2014. Washington, D.C.: Risk Assessment Forum, Office of the Science Advisor, USEPA.

Appendix A

The following definitions were taken from PMBOK Guides, NASA, and EPA documents.

PMBOK Guides:

Risk: An uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives.

Monte Carlo Simulation: An analysis technique where a computer model is iterated many times, with the input values chosen at random for each iteration driven by the input data, including probability distributions and probabilistic branches. Outputs are generated to represent the range of possible outcomes for the project.

Risk Acceptance: A risk response strategy whereby the project team decides to acknowledge the risk and not take any action unless the risk occurs.

Risk Appetite: The degree of uncertainty an organization or individual is willing to accept in anticipation of a reward.

Probabilistic Risk Assessment Procedures Guide for NASA Managers and Practitioners:

Probabilistic Risk Assessment: is a comprehensive, structured, and logical analysis method aimed at identifying and assessing risks in complex technological systems for the purpose of cost-effectively improving their safety and performance.

Model: (of the world) A mathematical construct that converts information (including data as a subset of information) into knowledge. Two types of models are used for risk analysis purposes, aleatory and deterministic.

Epistemic: Pertaining to the degree of knowledge of models and their parameters. From the Greek episteme (knowledge).

"Probabilistic Risk Assessment to Inform Decision Making: Frequently Asked Questions" (EPA):

Variability: refers to natural, inherent variation, variability is unavoidable, and cannot be reduced in the way uncertainty can.

Uncertainty: is the lack of understanding of the world, while unavoidable it can be reduced through additional investigation or collection of better information.

Sensitivity Analysis: the process of changing one variable while leaving the others constant to determine its effect on the output. This procedure fixes each uncertain quantity at its credible lower and upper bounds (holding all others at their nominal values, such as medians) and computes the results of each combination of values. The results help to identify the variables that have the greatest effect on exposure estimates and help focus further information-gathering efforts