Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen

doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P1587-cd

Methodology for Risk Assessment in Technology Incorporation in the Oil & Gas Industry

Marcos Vinicius da Silva Nóbrega

Petróleo Brasileiro/Petrobras, Brazil E-mail: marcos_nobrega@petrobras.com.br

André Luis Severino de Abrego

Petróleo Brasileiro/Petrobras, Brazil E-mail: andre.abrego@petrobras.com.br

Danilo Colombo

Petróleo Brasileiro/Petrobras, Brazil E-mail: colombo.danilo@petrobras.com.br

The Oil & Gas sector is continuously seeking new technologies aimed at increasing well productivity, reducing costs and operational risks. In addition to the challenges directly associated with technological development, there is an important issue related to the incorporation of new technology: on one hand, there is a desire to apply the new technology as soon as possible, anticipating the capture of its benefits; on the other hand, there is the risk of not having it available by the intended date, delaying production and leading to losses that may exceed the promised benefits. This issue is exacerbated by the high lead time required between contracting and the availability of the necessary technologies.

The risk of readiness can be reduced by considering contingency routes. However, if this strategy is not carefully crafted, it may come at the cost of significantly reduced expected benefits.

Utilizing new techniques and computational tools to develop dynamic models that assist decision-making is one of the main approaches to adapting to constant changes and the inherent complexities of technological development and technology incorporation. These models allow for a more accurate assessment of risks and opportunities, contributing to the effectiveness and efficiency of innovation processes. Furthermore, the implementation of robust metrics and probabilistic representations of risks enables better management of project portfolios, aligning them with the strategic objectives of organizations and aiming to maximize returns on their investments.

It is noteworthy that companies have generated large volumes of data on the evolution of maturity and risk metrics, characterizing the dynamics of their developments, which can be used in project analyses.

This paper presents a methodology to support decision-making during the planning, development, and incorporation of new technologies.

Keywords: risk analysis, simulation, technology development, technology incorporation, technology readiness level, project planning.

1. Introduction

The O&G sector is continuously seeking to increase production, reduce risk, and lower costs in both well construction and operations. It also faces the challenge of making technically and economically viable certain producing areas that were previously unfeasible. Some of these challenges can be addressed through process improvements; however, others can only be overcome by incorporating new technologies into wells and operations.

Although the benefits of new technologies are undeniable, the process of integrating them into operations brings new challenges. New technologies typically have long development timelines, and during this period, there is significant uncertainty regarding their availability and even their feasibility.

Therefore, while there is a strong desire to capture the benefits brought by these technologies, there is also the risk of encountering their unavailability, which increases project costs due to the need to mitigate the absence of these innovations, ultimately delaying oil production.

This risk is further exacerbated by the long lead times required for procurement, which necessitate early planning despite high uncertainties.

Adopting hybrid strategies that combine new technologies with conventional ones can mitigate risk; however, this approach increases costs, reducing net benefits.

It is evident, therefore, that production projects require a detailed study considering both emerging and conventional technologies to develop strategies that minimize risk while maximizing net benefits.

To achieve this, it is essential to assess, for all considered technologies (both new and conventional), the risks associated with their availability at the required time, their benefits, the impacts of their unavailability, and their interdependencies.

Additionally, it is necessary to establish a monitoring process to track the evolution of these risks, assess the performance of the adopted strategy, and revise it if needed (API RP 17N 2017).

To support risk analysis for each of the considered technologies, as well as for the entire set of technologies within the chosen strategy—which may include contingency routes and derisking approaches—a methodology have been developed, incorporating quantitative risk analysis.

2. Methodology

The proposed methodology consists of five steps:

(i) Modeling the probability of availability for each technological route involved in a production project.

(ii) Estimating model parameters.

(iii) Modeling the production development project, considering the new technologies to be incorporated.

(iv) Simulating the model.

(v) Analyzing the results.

The following sections provide a more detailed overview of each step of the methodology.

2.1. *Modeling the availability of a new technological component*

Technology Readiness Level (TRL) strongly influences uncertainties in technology development schedules (Dubos et al. 2008). Therefore, the development process was modeled as a sequence of activities corresponding to each TRL.

Thus, the development of a technology is modeled as a sequence of activities, starting with the one required to reach TRL_{i+1}, assuming the technology is already at TRL_i, and concluding with the activity required to achieve TRL 8, which corresponds to the stage of the technology's first availability (ISO 16290 2013).

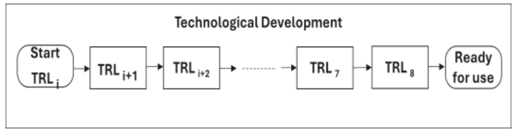


Fig. 1. Sequence of project activities based on TRL.

The probability of successfully completing a given development activity within a specific time frame is modeled using two factors: one representing uncertainty in the activity's progression rate and another representing the probability of success.

The first factor is the probability of completing the activity within a given time, conditional on its success, denoted as $P_C(t|S)$. The second factor, P_S , represents the probability of success in the activity.

Thus, the probability of successfully completing a technological development activity within a given time, $P_C(t)$, is given by:

$$P_{cs}(t) = P_c(t|S).P_s \qquad (1)$$

The probability $P_c(t|S)$ is obtained by integrating its probability density function $f_c(t|S)$ up to time *t*. Therefore, the probability of successfully completing a technological development activity within time *t*, $P_{CS}(t)$, is given by:

$$P_{cs}(t) = P_s \int_0^t f_c(t|S)\, dt \qquad (2)$$

2.2. *Estimating model parameters*

To determine the parameters of the distribution model characterizing schedule uncertainties for an activity, several approaches can be used:

They can be determined based on historical project data. These parameters can also be estimated based on expert judgment. Additionally, techniques can be applied to combine estimates derived from historical data with those based on expert opinions.

2.2.1. *Determining parameters through historical data*

The determination of model parameters based on historical data can be a good alternative when there is a sufficient number of similar projects in the historical data of previous projects.

Through this approach, for each activity in question (associated with the TRL), the durations of these activities in similar and successfully completed projects are determined.

With the collected data in hand and considering a set of models such as the Normal, Exponential, Log-normal, and Log-logistic distributions, a goodness-of-fit test, such as the Kolmogorov-Smirnov test, is applied to select the model that best represents the data.

Once the distribution is selected, parameter fitting is performed using a technique such as Maximum Likelihood Estimation (MLE).

Fig. 2 shows an example of historical data for the duration of the TRL5 stage and the fitting of the log-normal distribution to this data.

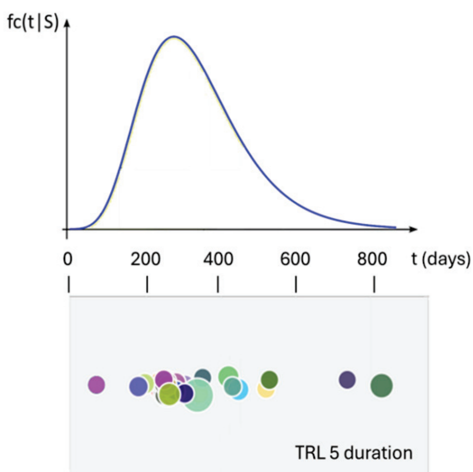


Fig. 2. Historical data of TRL5 completion time and fitted log-normal distribution.

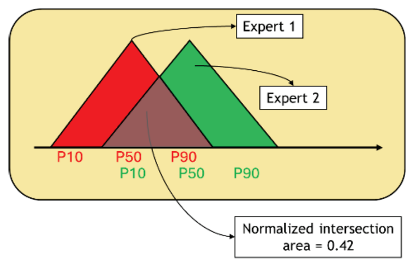
2.2.2. *Determining parameters through expert opinion*

When the project under analysis has particular characteristics that cannot be well represented by projects in the historical project database, it is possible to estimate the distribution that characterizes the schedule risk through expert opinion. For example, a group of experts consisting of technology developers and production project managers could be asked to estimate the time to complete the activity from an optimistic (10th percentile or P10), realistic (P50), and pessimistic (P90) perspective.

The elicitation employs fuzzy sets and similarity aggregation (Abreu et al 2020). The fuzzy set allows to handle uncertainty in the expert opinion and the aggregation.

The estimates from the different experts could be combined by assigning weights based on their experience and weights derived from the convergence of their responses (see Fig. 3).

Fig. 3. Derivation of the similarity matrix.



Similarity Matrix

	Expert 1	Expert 2
Expert 1	1.0	0.42
Expert 2	0.42	1.0

Adopting the log-normal distribution as the model, its parameters σ and μ are adjusted based on the estimated P10, P50, and P90 durations.

Alternatively, if the log-normal distribution does not provide a good fit for the estimated times, a log-logistic function can be used.

2.2.3. *Determining parameters through a Bayesian combination*

It is also possible to generate a model based on both types of information. For this, a Bayesian approach can be used. In this approach, the time distribution based on expert opinion is considered as the prior distribution. The activity times contained in the historical data would serve to update the previous distribution. With these definitions, a Bayesian update could be applied to account for the values of the evidence. Using the Bayesian approach will allow the constant update of completion probabilities for each step in the development of technology. Another advantage is the possibility of assigning different weights for different classes of data (generic data, expert opinion, specific data, etc.).

2.2.4. *Probability of success*

To determine the probability of success for each activity, expert elicitation can be used to directly estimate the probability of success.

It is also possible to adopt the AHP (Analytic Hierarchy Process) methodology (or any other multicriteria decision making) to produce an estimate of the probability of success for the activity, considering various risk aspects, appropriately weighted.

Table 1 presents an example of possible weights for several aspects impacting the probability of success.

Table 1. Aspects impacting the probability of success x importance.

Aspects	Importance
Existence of qualified and available suppliers	1 - Does not exist
	0.5 - Qualified but not identified as interested
	0 -Identified qualified and interested suppliers
Use of technology depends on authorization from external bodies	1 - There are dependencies with high difficulty of achievement
	0.5-There are dependencies and moderate difficulty of achievement
	0 - There are no dependencies or they have low difficulty of achievement
Prioritization of delivery within the project portfolio	1 - Not approved in the project portfolio
	0.5 - Approved with low priority in the portfolio
	0 - Approved with high priority in the portfolio
Existence of technology use outside Petrobras	1 - Not used in any industry in the world
	0.5 - Fully utilized onshore or in another industry different from O&G
	0 - Fully utilized in offshore O&G
Level of Innovation	1 - Disruptive
	0.5 - New generation
	0 - Improvement
Hierarchical Level	1 - System (by discipline: Well System, Surface System, or Submarine System)
	0.5 - Subsystem (Well: Completion, Well Structure, Surface: MCS, Chemical Injection System, HPU / Submarine: Umbilical, SCM, UTA, Production Pipeline, Christmas Tree, etc.)
	0 - Component (e.g.: wellbore, valves, chemical injection meter, etc.)

2.3. *Modeling the Field Development Project*

Knowing the risk model for each of the technologies involved in the production project, the next step in the methodology is to characterize how the production project depends on each of the planned technological routes. This characterization may include:

- Concurrent Routes – Development routes of the same technology that progress independently. They help deduce the risk of failure in the technology's availability. However, they may increase development costs.
- Contingency Route – An alternative route initiated after a decision is made based on the poor performance of the main route. The main route is interrupted. It reduces the risk without significantly increasing costs.
- Dependent Technologies – Technologies that are developed sequentially, based on some dependency.

Conventional technological solutions are also commonly found, both as concurrent routes and contingency routes, with no development risk but without the benefits offered by new technologies. In this case, the activities considered in the model are associated with the contracting and provision processes for the solution.

Fig. 4 presents an example of a set of technologies considered in a production project.

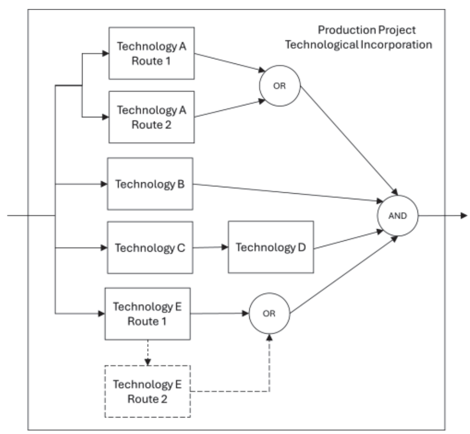


Fig. 4. Example of project detailing.

In this example, Technology A has two concurrent routes: Route 1 and Route 2.

Technology D is dependent on Technology C.

Technology E has a main route, Route 1, and a contingency route, Route 2.

The technologies A, B, C, D, and E must all be available for the Production project.

Along with the characterization of the dependencies and relationships between the technological routes, it is also necessary to provide the cost of each route as well as the benefits they offer.

It is also necessary to define, in order to enable the subsequent step of the methodology, the decision criteria for interrupting the execution of a main route and starting a contingency route. These criteria may combine the identification of failure in one of the development activities and the reduction of a threshold percentage in the probability of availability of the production project by the required date due to accumulated delays in the activities of a development route.

2.4. *Model simulation*

To assess the performance of the production project, a Monte Carlo Simulation of the project is performed, simulating N realizations of the project. In each of these realizations, the simulation traverses each activity of each route of each technological development associated with the project.

In each iteration of the simulation, for each activity in the project, draws are made for the duration and the result (success or failure) of that activity. These draws are made based on the duration time distribution and the probability of success for the activity.

After these draws are made, considering the initial time as the start date of the first activity of the project, the activities are processed in chronological order, calculating the completion date of each activity.

The “OR” logic is considered, which allows the subsequent activity to proceed once one of the input activities is completed, and the “AND” logic, which requires all input activities to be completed before moving to the next activity.

The draws for the result of the activity (success or failure) are also considered, which can invalidate its route in the technology project, making the production project dependent on concurrent routes or contingency routes, if they exist in the strategy.

A periodic check schedule should also be considered in the simulation to represent the intermediate evaluation moments of the risk in the development project, allowing for the simulation of decision-making events such as the cancellation of a main route and the start of a contingency route, if this structure is planned in the project strategy.

For each simulation iteration, the following are recorded:

- The project outcome (success or failure).
- In the case of success, the completion time.
- The incurred cost (present value) throughout the project.
- The paths taken (activities, routes).
- The benefit achieved (it is worth noting that conventional technology routes, although they reduce risk, decrease the benefits produced if used).

At the end of the N iterations, it is possible to derive, among other indicators:

- The project success probability.
- The distribution of the project completion date.
- The distribution of project cost.
- The distribution of achieved benefits.
- The percentage of contingency route activations.

2.5. *Analysis of the results*

The results of the simulation are of great importance to those responsible for the production project, as they allow the identification of risks and weaknesses in the strategy used by the project in advance. This enables adjustments to be made to the strategy to align the risks, benefits, and costs with the standards accepted by the company.

Through the analysis of the results, it is possible to determine the probabilities of successful completion by a specific required date, as well as the effectiveness of concurrent and contingency routes.

By varying the simulations, it is possible to assess how the decision-making criteria can affect each project indicator. It is also possible to compare the behavior of different strategies.

It is worth noting that simulations can be run before the project begins, but they can also be conducted during its development, allowing for the consideration of completed stages and updating the forecast for the project's indicators.

3. Cases

3.1. *Case 1*

This case study considered a set of six technologies under development, each contributing to the reduction of well construction duration.

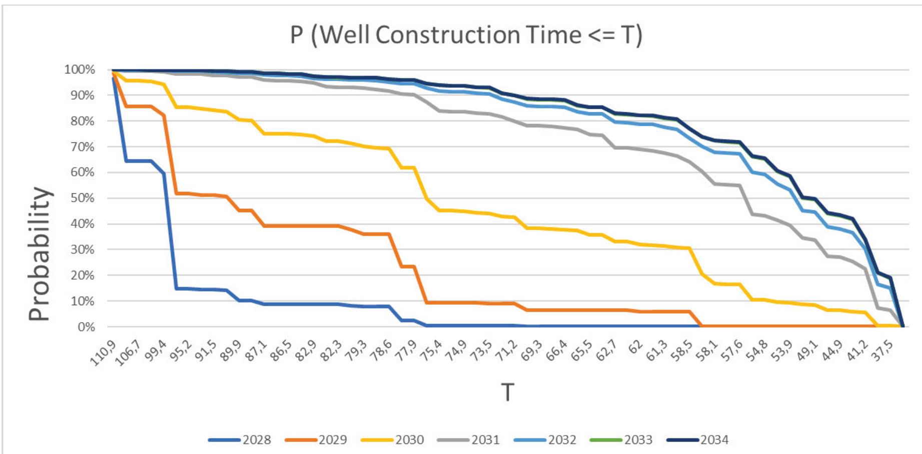
Each of them also presenting differentiated success probabilities and schedule risks.

The goal was to determine, to support the economic feasibility studies of the production project, the estimated value of well construction duration as a function of the required date, a key factor in determining well construction cost.

Based on expert opinions, the success probability of the development activities for each of the technologies was collected, along with estimates of the duration of their activities from an optimistic view (percentile 10 or P10), a realistic view (P50), and a pessimistic view (P90). Based on these estimates, the duration distributions of the development activities of these technologies were raised.

The simulation was run, providing the probability of each technology being available based on the required date. Based on these values and the reduction in time brought by each technology, the estimated value of well duration as a function of the date was determined. The result is presented in Fig. 5.

Fig. 5. Probability of construction time less than or equal to T for required dates (2028 to 2034).



3.2. *Case 2*

This study evaluated, for eight technologies at different development stages (different TRLs), the risks associated with their availability within a two-and-a-half-year timeframe, as well as its two constituent risk factors. The described methodology was applied, and for each technology, the probability of availability by the required date and its two constituent factors were determined: probability of success (atemporal risk) and probability of availability given success (schedule risk). The results are presented in Table 2. This segmentation of risk components allows for identification of their nature, enabling the study of appropriate risk mitigation measures.

Table 2. Probability of availability and its contributing factors.

Technology	Probability of availability	Success probability	Probability of availability given success (schedule risk)
A	0,0%	90,0%	100,0%
B	45,2%	90,0%	50,2%
C	95,0%	95,0%	100,0%
D	0,0%	90,0%	0,0%
E	0,0%	80,0%	0,0%
F	50,0%	50,0%	100,0%
G	90,0%	90,0%	100,0%
H	100,0%	100,0%	100,0%

3.3. *Case 3*

This case study addressed the development of a technological solution composed of three components. For the development of each component, several competing pathways were considered.

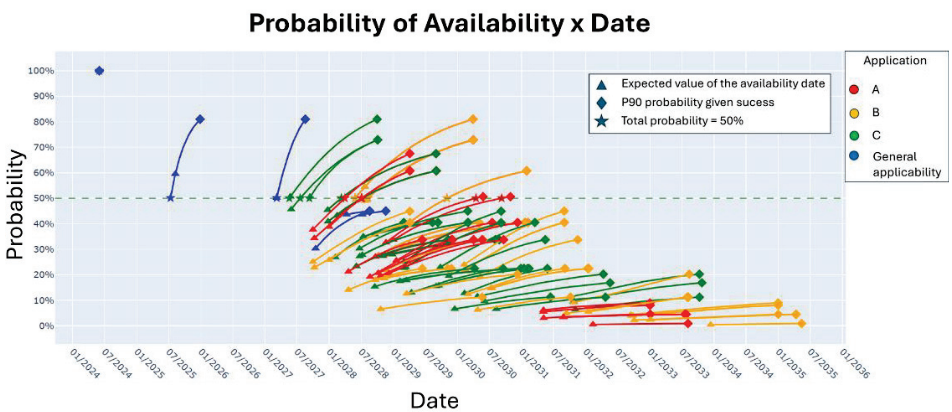
The objective of the analysis was to provide an overview of the availability risks for each potential solution.

As in Case 1, the probabilities of success and the time distribution for each activity of the routes were estimated based on expert opinions.

All combinations of routes were simulated, generating the probability availability curves for each solution as a function of time.

Fig. 6 presents a graph representing the risk of the evaluated solutions.

Fig. 6. Probability of availability x Date.



4. Conclusions and Next Steps

The methodology presented has been used for some project risk analyses and to support decision-making within the company.

Although based on simple concepts, the methodology enables the modeling of complex strategies, capable of producing a rich set of information that assists in the planning and management of projects. Among the benefits of the methodology are:

- The ability to combine the insights of experts with historical data in risk modeling.
- The possibility of identifying critical paths, as well as indicating the factors that contribute most to project risk (schedule uncertainties vs. probability of completing activities).
- The possibility of simulating different strategies and decision-making criteria aimed at improving project planning and execution.
- The potential to establish adjusted risk mitigation tactics based on the risks presented during project execution.

The software tool implementing the methodology is under development and will support the planning and management of technological developments as well as the planning and management of production projects involving the incorporation of new technologies.

As next steps, the inclusion of modeling for CRL (Commercial Readiness Level) advancements is being considered.

There is also ongoing research on the possibility of updating the time distributions for project activities, determined during the planning phase, based on the actual execution times of activities throughout the course of the project.

References

Abreu, D. T. M. P., Santos, J. R., et al. (2020) “Application of Fuzzy Logic and Expert Elicitation for Quantitative Offshore Well Integrity Data Collection.,” in ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering.

API Recommended Practice 17N (June 2017), *Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management*, 2nd Edition, 2017.

Dubos, G.F., Saleh, J.H. and Braun, R. (2008), "Technology Readiness Level, Schedule Risk, and Slippage in Spacecraft Design", Journal of Spacecraft and Rockets, vol. 45(4), pp.836–842. https://dx.doi.org/10.2514/1.34947

ISO 16290:2013. *Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria assessment*. Geneva: International Organization for Standardization, 2013.