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Planning and Estimating Risky Projects: Oil and Gas Exploration

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Abstract

Deterministic methods of planning and estimating projects tend to be inherently optimistic, for reasons set out in this paper.

After setting out the challenges of realistic planning of oil & gas exploration in PNG, the paper explores the reasons for inherent optimism in project planning. Use of probabilistic planning and estimating based on an Integrated Cost & Schedule Risk Analysis (IRA) version of the Monte Carlo Method (MCM) is shown to enable the user to take account of these reasons to produce more realistic forecasts of time and cost outcomes. IRA is contrasted with conventional separate cost and schedule risk analyses to highlight the benefits of the integrated approach.

The application of the IRA approach to produce realistic planning of exploration for oil and gas in Papua New Guinea (PNG) is then described.

While PNG represents extremes of time and cost uncertainty that demonstrate the value of probabilistic planning and estimating, the principles and approach are just as applicable to all kinds of projects where time and cost uncertainty are less extreme but still significant.

Introduction

Deterministic methods of planning and estimating projects tend to be inherently optimistic, for reasons set out in this paper.

After setting out the challenges of realistic planning of oil & gas exploration in PNG, the paper explores the reasons for inherent optimism in project planning. Use of probabilistic planning and estimating based on an Integrated Cost & Schedule Risk Analysis (IRA) version of the Monte Carlo Method (MCM) is shown to enable the user to take account of these reasons to produce more realistic forecasts of time and cost outcomes. IRA is contrasted with conventional separate cost and schedule risk analyses to highlight the benefits of the integrated approach.

The application of the IRA approach to produce realistic planning of exploration for oil and gas in Papua New Guinea (PNG) is then described, for individual phases of the exploration process and for integrated sequences of phases. Other benefits such as optimisation of earthworks and minimisation of contingency allocation for seismic survey campaigns are also described.

The Challenges of Hydrocarbons Exploration in PNG

Oil and gas explorer OGX has been actively exploring in Papua New Guinea since 2009 to aggregate natural gas reserves for LNG and to produce an early condensate and liquids production project from within its multiple petroleum exploration licence areas over almost 30,000 square kilometres. OGX has participated in various gas discoveries and plans a continuing seismic and drilling program through to 2015 to develop sufficient reserves for an LNG project.

Exploration work is challenging, with large distances, difficult terrain and virgin forests with few roads such that transportation by river and helicopter are the best logistical support options. Up to 10 metres of rain falls over nine months of the year in part of the licence areas.

All site work is performed using materials and equipment supplied by helicopters, which can only fly when the weather forecast allows completion of flights from the base to the site and back to base. Rainfall or low cloud base frequently prevent flight or permit only some hours of daylight to be used.

All materials and equipment, such as drill rigs, must be able to be disassembled into modules within the lifting capacity of helicopters up to the maximum capacity of a civilian version of the Chinook.

With only a handful of these heavy-lift helicopters available in the world and demand high, hire and hourly operating costs represent a very significant expenditure.

Drilling rigs suitable for use, including the ability to be transported by helicopter, are also expensive to charter and cost almost as much to have "warm stacked" (in modular form ready for transport to site) as they cost to operate. Yet a shortage of suitable drilling rigs and significant delay to mobilise a new contractor means that explorers try to retain such rigs warm stacked rather than relinquishing them between drilling assignments.

Logistical problems are substantial in the lengthy supply chain processes, typically consisting of:

- Transport of all required materials and equipment into PNG via a warehouse near the capital Port Moresby,
- Transferring the materials and equipment by vessel from there to one of two River Bases (for north or south licence areas) and then
- Transfer to sites by helicopter.

Tropical diseases such as malaria are a feature of the region. Engagement with local tribal communities is a necessity to provide employment, share the benefits of investment in exploration and enable activities to take place without active opposition.

OGX's Deterministic Planning and Estimating Experience in PNG

From their commencement of exploration in PNG in 2009, OGX used conventional planning and estimating to set their seismic surveying and drilling targets. They found that they could confidently forecast up to a couple of weeks ahead, but beyond that "linear programming" (expecting events to occur in proportion to their planned durations) tended to break down, schedules slipped, budgets driven by time-dependent costs were exceeded and targets were not achieved. In the face of this pattern, OGX was ready to consider alternative approaches.

Why Conventional Planning and Estimating tend to be inherently optimistic

Before continuing the OGX story, we need to consider why conventional planning and estimating, as used by OGX, were unable to provide realistic forecasting of outcomes. We will see that such methods strongly tend to be inherently optimistic, for the reasons set out below. While discussing these reasons, the Monte Carlo Method is described, as used for Integrated Cost & Schedule Risk

Analysis (IRA), because its use enables us to deal with and understand the inherent reasons for optimism built into deterministic planning.

1. Project plans are often created to meet pre-conceived targets and dates

This is like a perverse version of Stephen Covey's second habit (of highly effective people): "Begin with the end in mind". [1]

When the planning process is begun with preset dates or annual targets to achieve, it is highly likely that the plan will be made to fit the targets, rather than determining by first principles what the target dates should be from the buildup of the project plan activities, available resources and logic.

2. Avoidance of optimism is difficult when single values are assigned to task durations

Using project planning software such as Primavera P6 or Microsoft Project requires that the planner assigns a single value to each task's duration. Through this duration assignment process, linking the tasks with schedule logic and application of the critical path method, the software determines the end date of the project, along with all other early and late dates (hence the description of this as "deterministic planning").

In reality we rarely know exact durations, but rather, we are more likely to be able to identify a range of durations, as illustrated by the well-known example of being asked how long it takes to travel from home to work each day. Most of us would not give a single time, but instead may provide multiple answers:

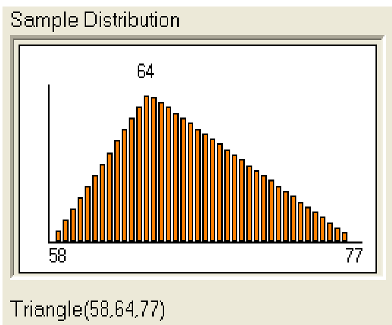
- If the weather is good and traffic is light, travel time could be as short as 30 minutes;
- If it is raining and traffic is heavy, it may take 60 minutes;
- If there is an accident or traffic signals were not working, it could take 75 minutes;
- But most of the time it takes about 45 minutes.

This set of answers defines a probability distribution based on three scenarios – Optimistic (30 minutes), Most Likely (45 minutes) and Pessimistic (60 minutes). In addition, a couple of risk events are provided (accident, traffic signal failure) that may happen from time to time.

Project plans contain many such activities, often in their thousands. Yet conventional planning requires that all tasks are assigned single durations. In reality it's impossible for a planner to take into account all the above and be able to assign a single duration value fully representative of the uncertainty. When combined with Reason 1 above, the deterministic planning process is thus likely to “err on the side of optimism”.

Use of Monte Carlo Method

If, instead of choosing a single set of duration values, we could replace each uncertain task duration by a probability distribution range, such as the two examples following, we could feel more confident that the inherent uncertainty in the identification and definition of task durations is being realistically expressed:



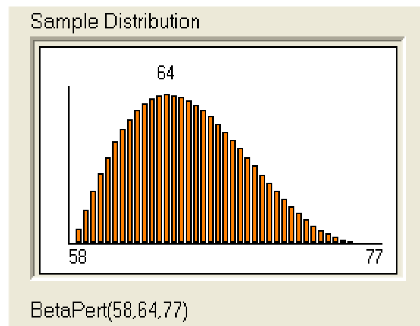


Figure 1 — Task 3-point probability duration distributions

The two examples are for the same three-point distribution task, with a Minimum (or Optimistic) duration of 58 days, a Most Likely duration of 64 days and a Maximum (or Pessimistic) duration of 77 days. The triangular distribution spreads more probability of occurrence toward the extremities compared with the Beta Pert distribution, which concentrates sampling probability more centrally. Other distribution shapes may also be used to express the uncertainty to match the nature and extent of uncertainty inherent in the estimates.

Using a mathematical technique known as the Monte Carlo Method (“MCM”), we can “run the project” many times over by randomly choosing values from all the task duration ranges. After sampling task durations from within their nominated distributions, we then calculate using the Critical Path Method (“CPM”) all the latest early dates for the tasks in the forward pass and the earliest late dates in the backward pass for the tasks.   The dates and float values from each “run” or iteration are stored. We may instruct the MCM software to run hundreds or thousands of times to explore the outcomes from all possible combinations of duration values from (as an example) the “travel to work” activity and all the other duration-uncertain activities, while ensuring that we sample the durations in conformity with the distribution limits and shapes such as shown above. That is, we choose sample values more frequently from around the peak probability “Most Likely” duration and proportionately less frequently from the extremities. The MCM software stores all the early and late dates from each CPM calculation (known as an MCM "iteration") and uses the stored information to produce results at the end of the simulation process from all the iterations.

Through this method, we will generate duration probability distributions for all the activities in the schedule, including the end milestone of the project, such as shown below, produced by Oracle's Primavera Risk Analysis™ ("PRA", formerly known as Pertmaster):

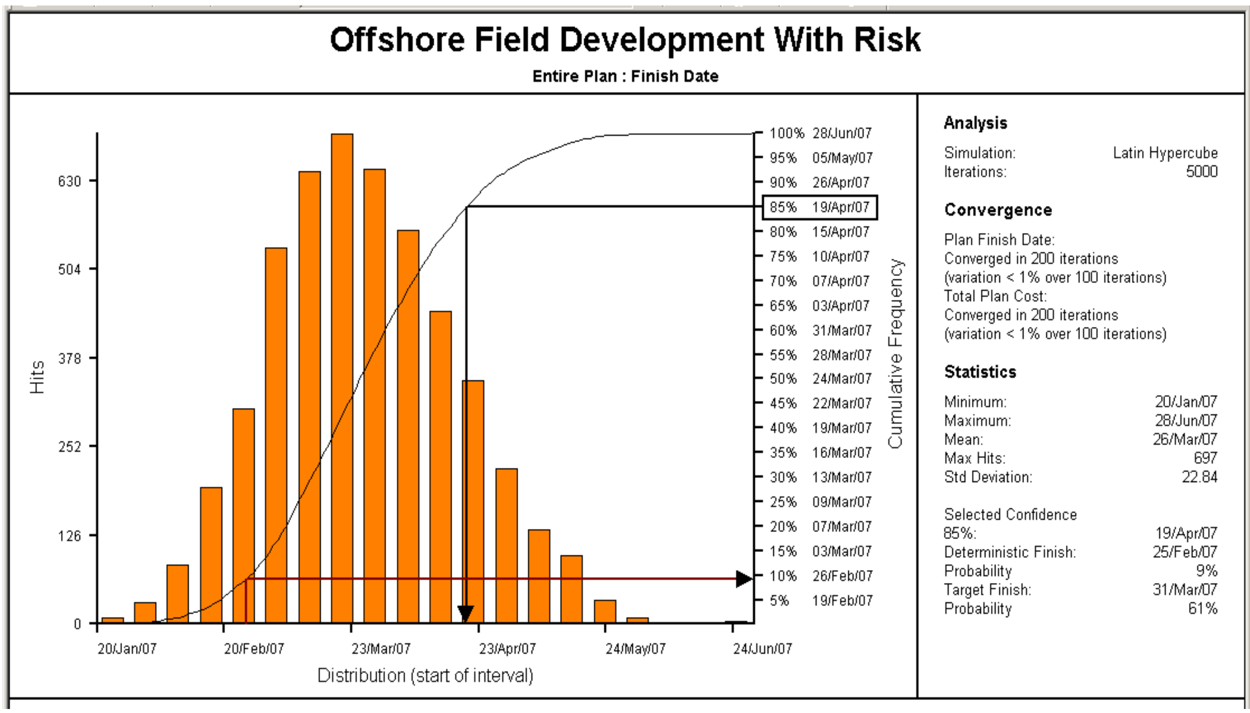


Figure 2 — Monte Carlo Schedule Risk Analysis Typical Outcome

The above histogram plots the ordered date outcomes of all the iterations, from earliest (left edge of chart) to latest (right edge), with each vertical bar representing the number of iterations ("Hits" shown on left vertical axis) out of the 5,000 run (see top right, under "Analysis") in which the Entire Plan finished between a date on the left edge of the bar and the right edge of the bar. The earliest Hit occurred on 20Jan07, the highest frequency bar was for Hits just prior to 23Mar07 and the latest hit occurred on 24Jun07.

If a cumulative curve is created by adding the number of hits per bar to each successive bar, so that the curve runs from 0 hits at the bottom left corner to 5,000 hits at the top right corner, the curve can be used to show how many hits out of the total are required to equate to a particular date. If we drop a vertical line from the point on the curve where 2,500 iterations have occurred up to that date, we have 50% of the iterations represented by that date, of the 24Mar07. **This is the probability that the project will finish on or before 24Mar07**. We can also see how likely the deterministic (planned) date of completion of the project is to be achieved, based on the ranges assigned to all the uncertain duration tasks. The deterministic date is shown in the bottom right hand corner of the chart (24Feb07) and it is shown by the red horizontal arrow toward the bottom of the chart, indicating a probability of 9%.

We could also choose a conservative percentage (such as 90%) to represent a date that is unlikely to be exceeded, in this case 26Apr07. For brevity, this is referred to as the P90 date.

So from a single date from the deterministic plan, through MCM simulation based on substituting ranges for single durations, we are able to understand how optimistic our planned finish is and what would comprise likely or conservative dates, often significantly later than the planned dates.

When costs are overlaid on the schedule and divided into time-dependent and time-independent and ranged (as described later in the paper), a similar histogram and cumulative curve for cost will be produced, reflecting the simultaneous analysis of cost uncertainty with time uncertainty.

3. The probability of finishing on time decreases as more logic paths overlap and converge

This third cause of inherent optimism is bound up in schedule logic. Where parallel paths converge to create a logic node, often represented by a project milestone, the probability of the milestone being achieved is dependent upon the probabilities of each of the parallel paths being completed to enable it to happen. This behaviour is called the Merge Bias Effect (MBE) and is described comprehensively by Dr David Hulett in his excellent book "Practical Schedule Risk Analysis". [2]

Its effect can be explained by use of a simple illustration. If we have two identical strings of activities and resources to do them, each with a 20% probability of being finished by the target finish date, what is the probability of both being finished by that date? The problem and solution are shown below in Figure 3:

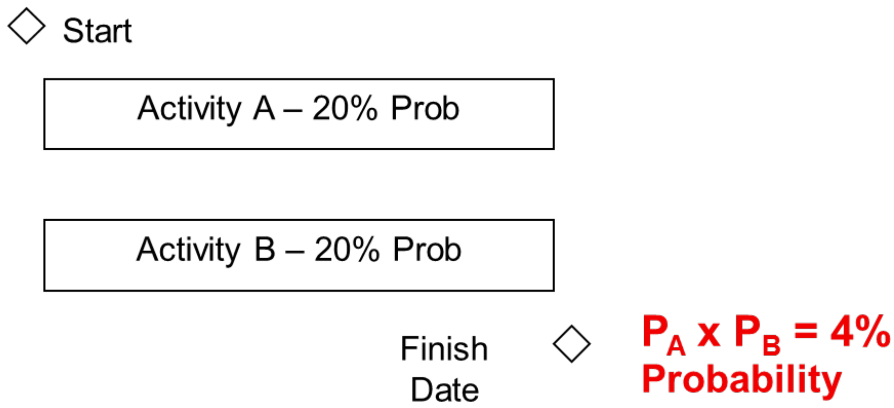


Figure 3 — Merge Bias Effect on parallel logic paths

The probability of all converging parallel paths finishing by the planned Finish Date is the product of the probabilities of each of the paths being finished. It is analogous to the probabilities of throwing dice.

The probability of throwing one six with one die is 1/6 (equivalent to a single-path schedule).

The probability of throwing two sixes with two dice is 1/6 x 1/6 = 1/36 (equivalent to a two-parallel-path schedule).

The MBE is a principle reason for projects being completed late. Although the MBE has been known about since the early 1960s [2, page 105], it is not at all obvious from deterministic planning, but becomes very apparent when MCM probabilistic planning is used.

Not only is this a primary and major reason for complex projects running late, but it is also the reason why delaying activities so that more and more overlapping parallel paths are being executed simultaneously results in overruns: the paths each decrease in probability of completion by the planned dates, but the probability of the milestone node being completed is driven down more by the low probabilities multiplying together.

4. Exclusion of allowance for risk events in project plans is unduly optimistic

We know from the time to get to work example cited earlier that risk events such as traffic accidents or other intermittently occurring events are less than certain to occur, perhaps unlikely or even rare, but that when they do occur, they substantially increase the trip duration.

Because there are many such activities in complex project schedules for which risk events are a natural part of the risk profile, allowance for their probabilistic occurrence is an important means of providing sufficient schedule contingency to make the probabilistic forecast schedule resilient enough that even if risk events not in the risk register were to occur – so called ‘unknown unknowns', the risk adjusted schedule would still provide adequate contingency to absorb the impact without schedule overrun.

While any one risk event is not certain to occur, over the whole project, provided the process has been thorough, risks in the register should occur in a pattern similar to the forecast.

By use of MCM, the occurrence of risk events can be modeled both in their uncertain impact range (using three-point impact distributions) and their probability of occurrence (appearing in the iterations in proportion to their estimated frequency).

Under risk events we could also consider weather uncertainty as an important risk input often not done well. By analysis of relevant weather data as it varies over the year it is possible to provide probability distributions for a range of weather impacts for each month of the year, forecasting the number of days per month which will be non-work days due to weather, or for even smaller intervals, say hours per day.

It is possible to model weather variability and downtime due to rainfall, wind and high temperatures, provided relevant weather records are available and criteria for non-work conditions are clear. In the case of PNG exploration, both rain (extreme for around 9 months per year) and cloud cover affect and hamper helicopter access to sites. For realistic schedule and cost forecasting these effects must be modeled. Probabilistic calendars are a very useful tool in MCM, allowing the project schedule activities to move around over a backdrop of weather uncertainty.

Conventional Quantitative Risk Analyses versus Integrated Cost & Schedule Risk Analysis

We have seen above how project plans tend to be optimistic, due to a range of reasons when created using deterministic planning tools, and that MCM Simulation offers capabilities to take account of these factors.

While the analysis so far has focused on project planning and factors affecting it, because of the strong influence of time-dependent costs on total project costs, particularly when costs overrun, it makes sense to combine analysis of time-uncertainty with analysis of cost-uncertainty. [3]

Integrated Cost & Schedule Risk Analysis

The argument and process for combining time and cost uncertainty in a simultaneous MCM analysis can be summarised as follows:

- Projects involve the use of materials and expenditure of effort through resources organised to produce agreed deliverables within a defined time period.
- The period of time is calculated through application of the critical path method to the activities devised to organise the effort to produce the deliverables.
- There is uncertainty associated with the time required for the resources to perform the work, the amounts and types of resources required and the costs of those resources.
- In addition, there are risk events that may or may not occur but if they do, that may change the time and/or cost of completing the project.
- The costs of the materials and resources are a mixture of time-dependent ("variable") and time-independent ("fixed") costs, all of which will be uncertain before the start of the project.
- If the time dependent costs can be applied to the schedule in activities that overlay the corresponding scope activities and vary in duration according to the duration of the scope activities, those costs will be accurately captured. Uncertainty in rates identified by Subject Matter Experts (SMEs) can also be incorporated
- If the time-independent costs are also overlaid or mapped into the appropriate scope sections, with their uncertainty expressed in ranges identified by SMEs these costs can also be realistically assessed.
- Adding in risk events from the project risk registers with time and cost impacts incorporates the known risks that could affect the project goals. The risk events could be opportunities or threats and could affect multiple activities in the project. They may also be mapped into the cost-loaded schedule as risk factors that affect groups of activities to reflect such things as productivity, quantity uncertainty or market conditions.
- Probabilistic escalation curves may also be incorporated to take account of uncertain rates of increase of significant cost inputs to the exploration budget forecast, such as drilling consumables.

Separate Schedule and Cost Risk Analyses

While the above factors and process may seem logical enough, the development of cost and schedule risk analyses has been marked by separate development by separate groups of practitioners and different tools. A recently eponymously titled book on the subject of Project Risk

Management, which covers qualitative and quantitative risk analysis very well and argues convincingly for the use of integrated cost and schedule risk analysis, asserts that it is standard practice to run schedule and cost risk analyses separately. [4]

The traditional approach has been to perform a Schedule Risk Analysis (SRA), usually on a highly summarised "Proxy Schedule", incorporating the various sources of time-uncertainty and may also add in time-impact risk events. The SRA output is used to produce a cost allowance for schedule risk contingency, assuming an average or perhaps maximum rate of cost expenditure per unit time.

This schedule contingency allowance is then added to a separate Cost Risk Analysis for the project, which includes the various sources of cost uncertainty and may also incorporate cost impact risk events, as well as costs extracted from a Trend Register to reflect the latest information on the forecast cost. Often the items on a trend register reflect cost impacts of delay risk and uncertainty.

Objections to separate analyses

Apart from being an indirect approach to schedule impact, such a methodology separating schedule and cost risk analyses prevents the analysis from revealing the importance of delay uncertainties and risks in driving project cost.

Many of those that develop MCM schedule models argue for small summary models, even for large and complex projects. Originally based on the limitations of early SRA tools such as @Risk for Project which could not handle large numbers of activities in a reasonable simulation time, such arguments in favour of small models state they avoid unwanted schedule complexity. But this approach, by ignoring the MBE, produces falsely optimistic schedule analyses.

Objections to integrated MCM models overcome

The first MCM tools that could handle both schedule and cost risk analysis were relatively slow and could not cope with more than a low number of activities.

With the advent of more powerful tools such as Pertmaster / PRA and associated software to manipulate large numbers of activity ranges and cost line items using pivot tables, and rapidly build large-scale schedule and cost correlation models, these limitations have been removed and IRA models can be handled with several thousand activities and corresponding numbers of cost line items. Careful use of correlation models and risk factors is able to overcome the tendency in large schedule to produce narrow distributions, known as the Central Limit Theory.

In addition, a risk management tool was developed as a single-user Enterprise Risk Management database application to manage the complete risk and project lifecycles, with added features to map risks into PRA cost-loaded schedules with control over the apportionment of impacts of cost and schedule threats and opportunities in individual and multiple mappings to tasks.

This fully integrated cost and schedule risk analysis approach, developed over 7 years, proven on many projects from a few million dollars to many billions and combined with sophisticated probabilistic weather modeling, was made available to OGX to deal with their highly uncertain planning and estimating environment in PNG.

Use of "Unit Operations" approach to model Oil & Gas Exploration in Papua New Guinea

The IRA approach was proposed to OGX as a capable means to deal with the high levels of time and cost uncertainty inherent in their exploration of the Western Province of PNG. The creative approach taken by OGX was to step back from applying the methodology to a particular licence area. Instead OGX divided up the exploration process into its various stages and decided to examine each stage as a stand-alone project.

Generic "Template Projects" were planned for three of the "Unit Operations" of Oil & Gas Exploration, comprising:

- Drilling Pad Site Construction
- Moving and Assembling Drilling Rig
- Drilling

In addition, stand-alone Seismic Survey plans were developed for each campaign.

The only significant stage omitted was Seismic Interpretation, because it is not easily reduced to a set of variables. Instead, it was assumed that seismic survey information as an input to the Interpretation process produced recommended sites for drilling around 6 months later (slightly less for optimistic, slightly more for pessimistic cases).

Each Unit Operation was carefully planned, a generic schedule produced, refined to its simplest (but no simpler) and workshopped with SMEs to obtain their opinions on the duration ranges of the tasks in each plan, along with risk events from existing risk registers, or based on the SME's experiences of the work.

Where appropriate, risk factors describing the underlying sources of key uncertainties (such as the quantity of earth to be moved in site construction, or the depth of the well for drilling) were identified, and their relationship to the expected duration and cost of specific tasks within the plans quantified. In this way, the generic templates were able to be modified based on preliminary information to provide more accurate characterisations of specific sites.

Overlays of fixed and variable costs, appropriately split and ranged were applied in accordance to the levels of resourcing considered appropriate.

Risk Events with time and cost impacts were mapped into the schedule at the applicable stages of the work.

Analysis

Drilling data was made available by OGX and statistically analysed to separate normal ranges of drilling progress (rates of penetration in different 'strata' or formations) from risk events that had occurred during previous drilling of wells.

Weather information was obtained and weather modeling developed to cope with down times of some hours per daylight allowable flying time (due to rain or low cloud levels), to enable realistic simulation of constraints on delivery of equipment, supplies and personnel to sites by helicopter.

MCM analysis was performed on hourly IRA schedule models rather than daily schedules, to increase the precision of the modeling.

The duration and cost ranges, risk factors and risk events were then applied to the template plans and MCM analyses produced for time and cost to complete each generic project.

Typical probabilistic time and cost forecasts were generated from the IRA modeling.

These were then available for combining & customising for real projects.

Stand-alone estimating for funding approval

Each of these "generic IRA models" was then available for stand-alone use in forecasting realistic time and cost forecasts for future corresponding real projects, by substituting real durations and costs for the generic ones. This has been done on a number of occasions for site well-pad construction and for drilling. In addition, several seismic survey campaigns have been probabilistically planned and estimated.

The approach has been adopted to enable OGX to ensure that proposed operations have been carefully planned and realistically estimated, to meet conservative criteria before funding is approved.

Special Lesson from Seismic Survey Campaign Planning

A valuable lesson was learned from comparing probabilistic planning of a seismic campaign across multiple licence areas, treating each permit area as a separate project (as OGX has different equity partners in different licence areas), compared with treating the whole campaign as a single project. In the first case the budgeted time and cost contingencies had to be proportionately larger for each permit area, because the total survey **quantity** (measured in kilometers of leads surveyed) in each licence area was relatively small, whereas when the whole campaign was combined into one, the time and cost contingency could be proportionately significantly smaller, because the total survey quantity became larger. This is a statistical consequence of increasing the scale of the work.

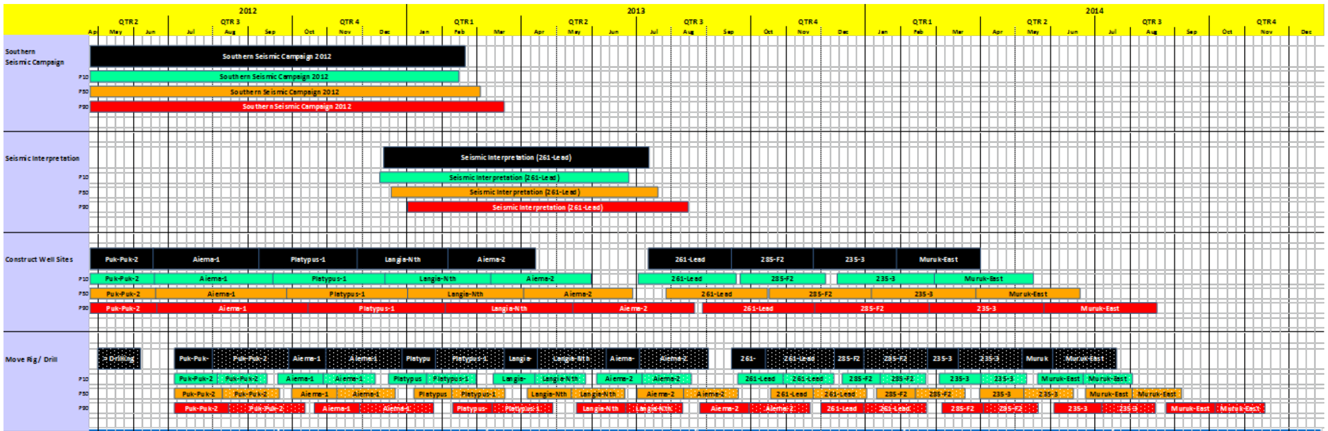
It did require that each of the junior partners in the various affected licence areas had to agree to share both costs and benefits. So if the work were completed faster in Licence Area "A", the savings in time and cost would go into the campaign "pool" for sharing between all the Licence areas, just as overruns similarly had to be shared. Overall, all partners benefit.

Integrated analysis combining multiple "Unit Operations"

A further integrated approach, from the point of agreeing on the location for several drilling sites has been used to examine extended operations over several cycles of Site Preparation, Rig Move and Drilling.

The generic sub-projects and tasks were combined and linked at various probability levels to explore whether any gaps opened up.

The following figure illustrates this approach:



Key Results	P10	P30	P50	P70	P90
Plan Duration	824d	848d	867d	890d	934d
% Downtime	3.3%	8.5%	11.8%	14.7%	18.6%
Days Downtime	27d	72d	102d	131d	174d

Figure 4 — Use of IRA for Rig Downtime Analysis

Figure 4 shows an exploration campaign ranging from Deterministic (black), through P10 (green), P50 (orange) and P90 (red), each tracking progress through:

- Seismic Surveys, followed by
- Seismic Interpretations (not included in MCM analysis, but with increasing timings for increasing pessimism), followed by
- Well-sites construction, followed by
- Combined Rig Move and Drilling.

The analysis shows that the Deterministic plan had no gaps between drilling campaigns, but as the basis of forecasting became more pessimistic, increasing (expensive) rig down time opened up as planning becomes more pessimistic, due to resource bottlenecks, revealing opportunities to optimise the planning and minimise the rig 'warm-stacking' time.

(Note that the above planning shows drilling activity that did not eventuate, including wells with conceptual names only. However it demonstrated the need for probabilistic forecasting and de-bottlenecking.)

Before and After Probabilistic Time & Cost Planning

In the challenging environment of PNG, OGX was quite good at short-term deterministic planning (say a 1 week look-ahead), where single risks could be covered and targets achieved.

But for longer term planning where multiple risk events are quite likely to occur and primary and secondary impacts may compound the adverse schedule consequences, the deterministic schedule quickly loses its usefulness.

Given the long and expensive supply lines and the high daily cost of equipment and transport, the cost consequences of such unplanned delays rapidly become substantial

By using the "Unit Operations" fully risked and costed approach incorporating the typical risk events previously encountered, OGX has been able to incorporate allowance for multiple risk events and time / cost uncertainties in their planning and estimating and greatly improve their ability to remain on track.

Outcomes from adoption of the IRA Approach

By simultaneously taking account of time and cost uncertainties through the use of IRA, OGX is able to generate consistent time and cost forecasts that are aligned with each other.

Planning and estimating have become more realistic as they are based on conservative probability levels of time and cost contingency.

Discipline managers aim to achieve P50 time and cost results or better.

Some examples of the use of the IRA analysis by OGX for PNG:

- Seismic survey outcomes are now much closer to initial planning – recent surveys have been completed very close to probabilistic budgeted forecasts.
- Planned drilling rates are now based on probabilistic ranges statistically derived from real data obtained from previous wells drilled in PNG and distinctions are made between normal progress ranges and delays due to risk events.
- Site construction is planned on the basis of optimising cut and fill volumes and weighing up costs of flying in an extra grader or working a grading night shift versus benefits of a better drilling location or a faster completion of the site, critical in such poor-weather conditions.
- Probabilistic forecasts of multiple sequenced wellsite construction, rig move, and drilling processes have helped to identify potential bottlenecks, resulting in changes to execution strategy to optimise cost and schedule outcomes.

Examples of actual results versus probabilistic forecasts will be provided in the Presentation of this Paper, for various "Unit Operations". These illustrate the fact that OGX is planning and meeting its targets better, helped by the use of IRA.

While PNG represents extremes of time and cost uncertainty that demonstrate the value of probabilistic planning and estimating, the principles and approach are just as applicable to all kinds of projects where time and cost uncertainty are less extreme but still significant.

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Author Photographs

Name	Photograph
Colin Cropley	
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