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Optimized Exploration Planning

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Abstract

The process of exploration planning in the oil and gas industry has historically been time-consuming and inefficient with limited information and large uncertainties to contend with. How does an oil and gas company take a set of exploration opportunities stored in disparate systems across the organization and combine them into a single, optimized forward exploration plan? This paper will examine the current industry processes in exploration planning and compare these with the benefits of an integrated solution with direct links from the subsurface to commercial to identify and track key parameters over time for business planning decision making.

This paper will first discuss the industry challenges and current practices in exploration planning. The proposed solution will then be defined as a shared repository of opportunities, consistent capture and quantification of subsurface risk and uncertainty linked with the quantification of potential hydrocarbon recoverable ranges, economic analysis across different fiscal regimes and stochastic portfolio optimization. The paper will then look at optimizing a sample set of exploration opportunities and examine the results and benefits gained after deployment at an integrated national oil company.

The integration of risk and uncertainty from the reservoir properties through to stochastic portfolio optimization based on project timing and working interest is a unique solution compared to the ″siloed″ and disconnected approach common in the industry. During this project, a shared understanding of risk and uncertainty from the subsurface through to the economic evaluation was observed throughout the asset teams and planners.

The implementation and execution of the proposed solution improved the efficiency of the exploration decision-making process and the management of the company's exploration portfolio. Integrated exploration planning leads to significant improved overall portfolio revenue at reduced risk and costs. The proposed solution is applicable to any mid- to large-sized oil and gas company with a number of exploration opportunities to choose from for inclusion in their portfolio.

The solution's value lies in the consistent approach to directly link key risks and uncertainties in the subsurface properties of the reservoir all the way through to the commercial evaluation of a portfolio of exploration opportunities. The result of this approach is optimal decision making and increased efficiencies in exploration business planning due to more thorough understanding and mitigation of key risks and uncertainties affecting the success of exploration opportunities.

Introduction

The different stages of the development of oil and gas assets include exploration, appraisal, development, production and abandonment. The exploration and appraisal phase of oil and gas assets has historically been a very risky venture for investors. These risks start with geological uncertainty around key reservoir parameters and move to increasingly complex economic and development models that carry their own technical, operational and geopolitical risks with no guarantee of successfully finding hydrocarbon resources. Richmond Energy Partners studied $40B in exploration capital invested since 2009 and found that technical success rates had dropped from almost 60% to under 50% and commercial success rates had dropped from over 40% to 30% over that time frame as shown in Fig. 1 below (Myers 2015).

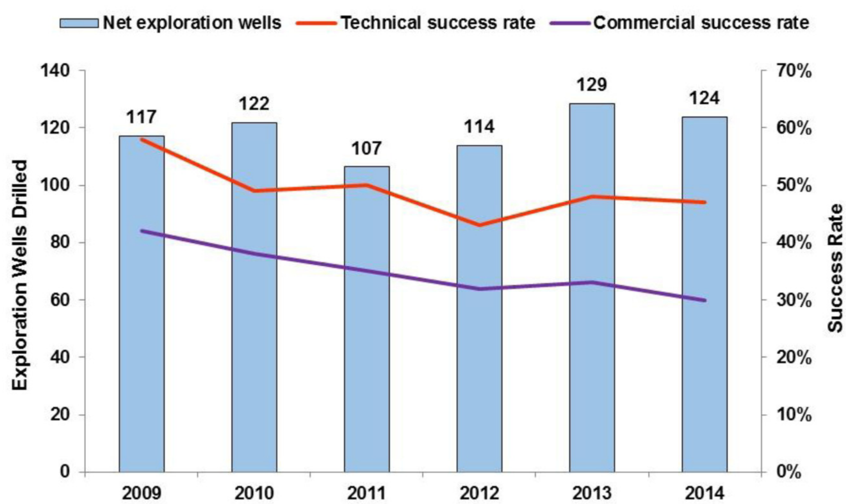

Figure 1—Net Exploration Wells and Success Rates - REP40. (Copyright: Richmond Energy Partners) (Myers 2015)

Similarly, frontier exploration success rates were even lower with technical success at 33% and commercial success at just 10% when averaged over different play types (offshore deep, offshore shallow, onshore) as shown in Fig. 2 below (Myers 2015).

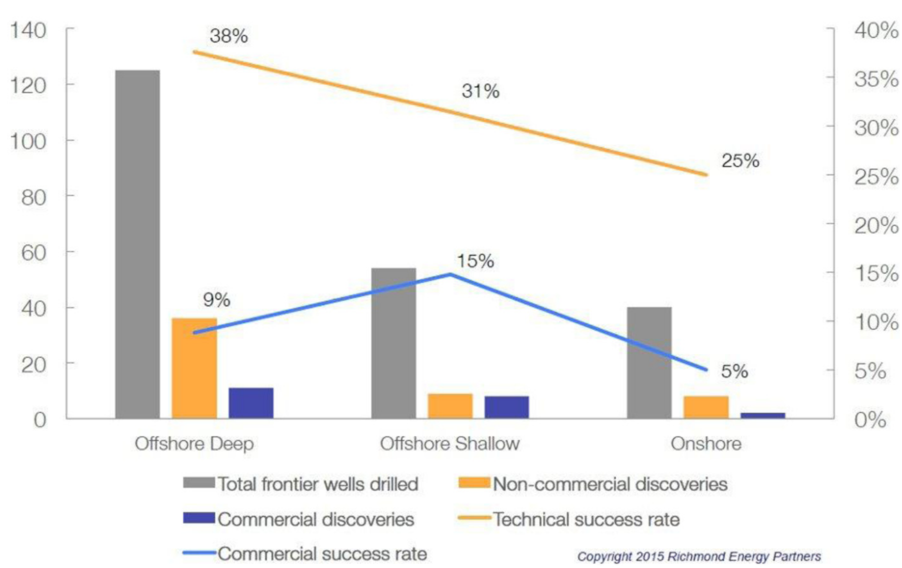

Figure 2—2009-2014 Frontier Drilling Success Rates by Water Depth. (Source: Wildcat database February, 2015) (Myers 2015)

This lack of success cannot solely be attributed to volatile commodity prices but to a decreasing success rate for exploration and frontier wells driven by increasing complexity and larger finding and development costs for bringing hydrocarbons to market. Since 2006, exploration capital has increased over 72% while overall production has increased just over 6% in a Price Waterhouse Coopers (PWC) study of 74 of the largest oil and gas companies by market capitalization (Cooke 2013), as shown in Fig. 3 below. In a range of forty selected mid-cap and large cap E&P companies, average drilling finding costs have shot up, from an average $1.0/boe between 2009 and 2012 to $1.8/boe in 2013 and $3.1/boe in 2014 – an increase of 210% (Myers 2015). Another take on the decrease in industry success rates was that there was great potential upside in a high oil price scenario but a low downside due to the refunding of exploration expenses through the fiscal regime thus encouraging the company to explore higher risk plays. This has now fundamentally changed since the upside has vanished in the current oil price scenario.

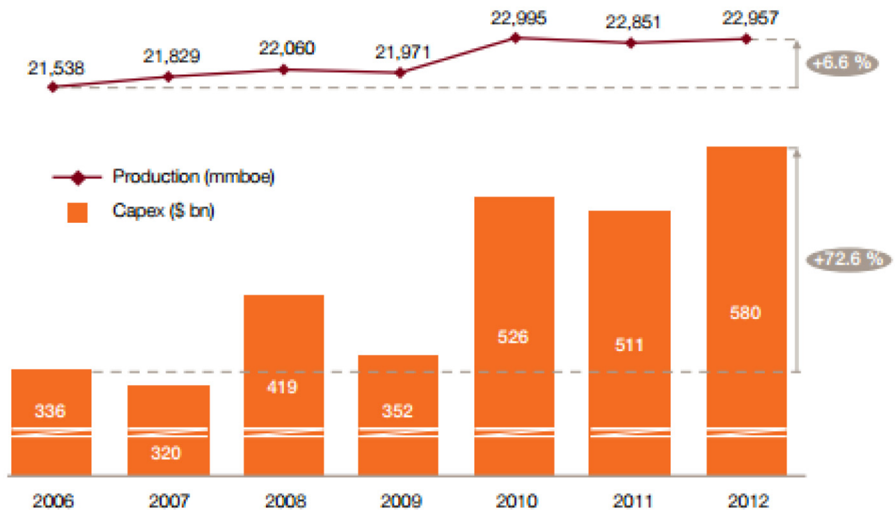

Figure 3—2006-2012 Exploration Capital and Production Growth (Cooke 2013)

This paper will examine the current industry processes in exploration planning and compare these with the benefits of an integrated solution with direct links from the subsurface uncertainties to commercial allowing tracking of key parameters over time for investment decision making. It will look at optimizing a sample set of exploration opportunities and examine the results and benefits gained after deployment of the proposed solution at an integrated national oil company.

Current Methods and Challenges in Exploration Planning

Due to its inherent nature of trying to understand and quantify the unknown, there are key uncertainties related to original or remaining volumes in place (OVIP and RVIP) and economic parameters (project revenue, development costs, after tax cash flow) in the exploration phase. As the level of understanding in the reservoir increases, these key uncertainties typically decrease (or can be mitigated) and the importance of the uncertainties related to hydrocarbon resource extraction methods and recovery factor increases. The situation is more critical in offshore fields and for heavy-oil reservoirs, where investments are higher and there is typically lower operational flexibility (Myers 2015).

During the early sixties, decision and risk analysis in the oil and gas industry consisted of defining resource probabilities and trying to understand how they affected the recoverable amount of hydrocarbons. During the eighties and nineties, advanced statistical analysis methods were first applied using different risk estimation techniques such as lognormal risk resource distribution and Pareto distribution applied to petroleum field-size data in a play (Suslick et al. 2009). Historically, the most common form of asset valuation has been the standard discounted cash-flow (DCF) analysis – only a handful of petroleum companies have experimented with other valuation approaches to overcome several limitations imposed by the DCF approach (Suslick et al. 2009). More recently, petroleum exploration decision theory has been defined as a series of related and possibly dependent investment decisions based on whether to acquire additional technical data or petroleum assets. Based upon these premises, exploration can be seen as a series of investment decisions with associated success and failure probabilities made under decreasing uncertainty. Every exploration decision involves considerations of both risk and uncertainty on recoverable resources as well as timing and scheduling of future investments and expected cash flows (Suslick et al. 2009). An example would be to model an exploration well with different combinations of drilling and facility elements in a decision tree approach based on the success or failure of each chance node to define an asset development plan (Back and Kirk 2012).

However, these methods were inconsistently adopted across the industry and sometimes not even within a single company's exploration asset teams and functions. Economists and engineers could use a combination of single outcomes, scenarios, decision tree expected outcomes, best estimates or weighted averages combined into an evaluation of the economic benefits of the project (Schulze et al. 2012). A majority of complex subsurface characterizations would then get reduced to a few expected outcome cases which were passed to the commercial analyst for further evaluation (Schulze et al. 2012). Consider an example with a simple exploration prospect. There is a 40% chance that it will be successful and if it is developed it will result in a net cash flow of $100M. There is a 60% chance that it will be unsuccessful and won't be developed. If it is not developed the sunk capital cost will be $20M. The expected value of this project is then (100)*(0.4) - (20)*(0.6) = $28M. Very few companies have moved their exploration project analysis to a fully integrated stochastic approach with standardized methodologies all the way through to the commercial evaluation for all opportunities. The end result has been a piecemeal and disconnected approach with non-standardized data stored in disparate software systems. In large oil companies there has been a long history of working in silos which has prevented cross-discipline workflows and the proper handling of key uncertainties.

Once each exploration opportunity was characterized and the commercial benefits understood a simple ranking by an economic metric such as discounted after tax cash flow was typically computed with the top performing projects included until the capital budget was consumed (Schulze et al. 2012). However, if market assumptions change drastically and rapidly - as they have done numerous times over the past few decades in the cyclical commodity-based oil and gas industry – project evaluations are often outdated before the annual planning exercise is completed resulting in a sub-optimal portfolio selection. This traditional planning approach did not allow interaction between projects or investment flexibility when new technology, fiscal regime or operational changes affected production or reservoir recovery rates. A few companies have started a more quantitative and integrated portfolio management approach to consider multiple metrics and project dependencies across both long term strategic planning and short term operations goals and ultimately select the most efficient exploration portfolio when assessed on a risk vs reward basis (Back and Kirk 2012).

Proposed Solution

The proposed solution will address the technical challenges and not specific organizational factors that may have an impact on successful deployment and adoption. The solution is defined as a central shared repository of opportunities, a consistent capture and quantification of subsurface risk and uncertainty associated with the reservoir parameters such as porosity and permeability. The result of this approach was an assessment of the range of potential hydrocarbon resources, standardized economic analysis of each reservoir across different fiscal regimes and stochastic optimization of the entire exploration portfolio to determine which projects should be pursued at what working interest and in which year.

The high-level vision for the solution is to:

- Capture subsurface risk and uncertainty for all exploration opportunities in a shared repository
- Categorize and evaluate each opportunity through specific shared criteria
- Standardize economic evaluations across multiple fiscal regimes
- Optimize and determine the most efficient use of capital to invest in a portfolio of resources

The solution is comprised of three pillars which will be outlined in more detail below.

- Exploration Prospect Risk Assessment
- Exploration Prospect Value Assessment
- Exploration Portfolio Optimization

Exploration Prospect Risk Assessment

The first pillar in the solution is the exploration prospect risk assessment. This assessment of risk means a definition of the probability of opening of a field which can be subdivided under probabilities of existence of the relevant groups or factors of risks. The assessment of resources means determination of range and character of volumes of hydrocarbons in the opening of a field. The first step is to build a geological model of the reservoir including an understanding of key parameters such as reservoir thickness, porosity, oil saturation and recovery factor that affect the volume and rate of hydrocarbons that can be extracted. Play and segment maps can be used to delineate spatial variation in chance factors and uncertain volumetric parameters that control product, initial volume in place and recoverables The next step is to define segments in the reservoir based on geologic and cultural boundaries and assign uncertain values to segment parameters such as thickness, porosity and saturation. These parameters are then combined with correlations and dependencies between variables and used in a stochastic Monte Carlo simulation to generate estimates of ranges of in-place, recoverable resources and an estimate of the chances of success and failure for each segment.

In addition, the exploration prospect assessment provides mechanisms to capture the geologist's understanding of individual reservoir layers, seal capacity, dual porosity systems, hydrocarbon indicators, fault blocks, formation volume factors as well as gas-oil and condensate-gas ratios. A detailed analysis is done to provide a more complete understanding of the subsurface. This deep geological understanding of the reservoir will ultimately lead to a volume distribution for different scenarios of recoverable hydrocarbons. A typical example below in Fig. 4 shows a prospect in the pre-exploration phase with seismic data evaluated by geologist and geophysics staff.

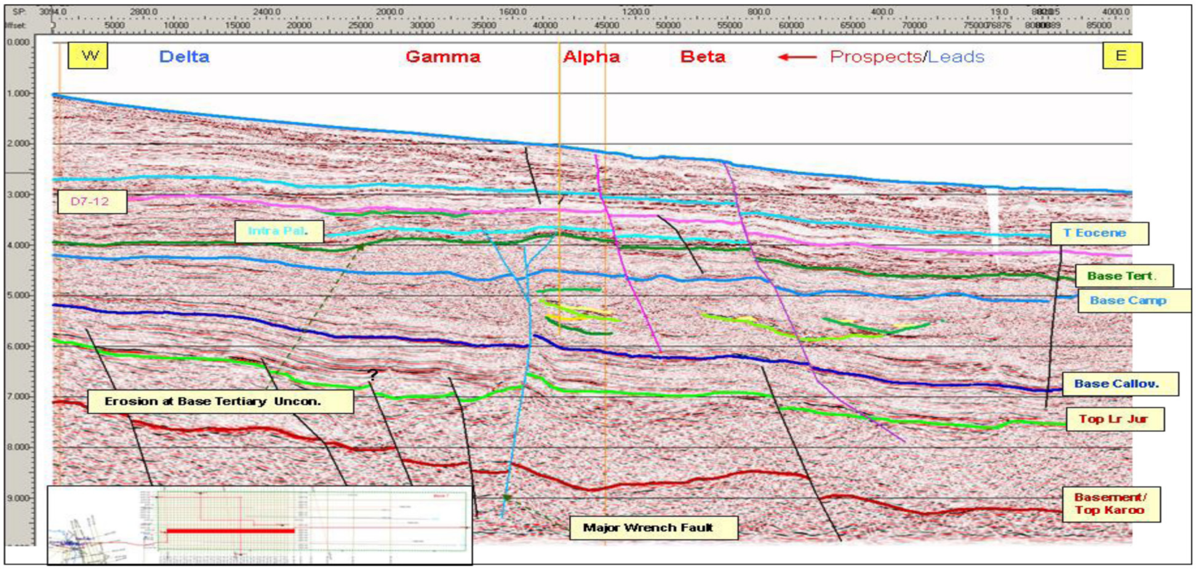

Figure 4—Example Prospect 2D Seismic Reservoir Simulation Model

From this information, geologic experts are able to estimate the uncertainties on key geological parameters to formulate a geological model including the risk model with uncertainty ranges on volumes in Fig. 5 below.

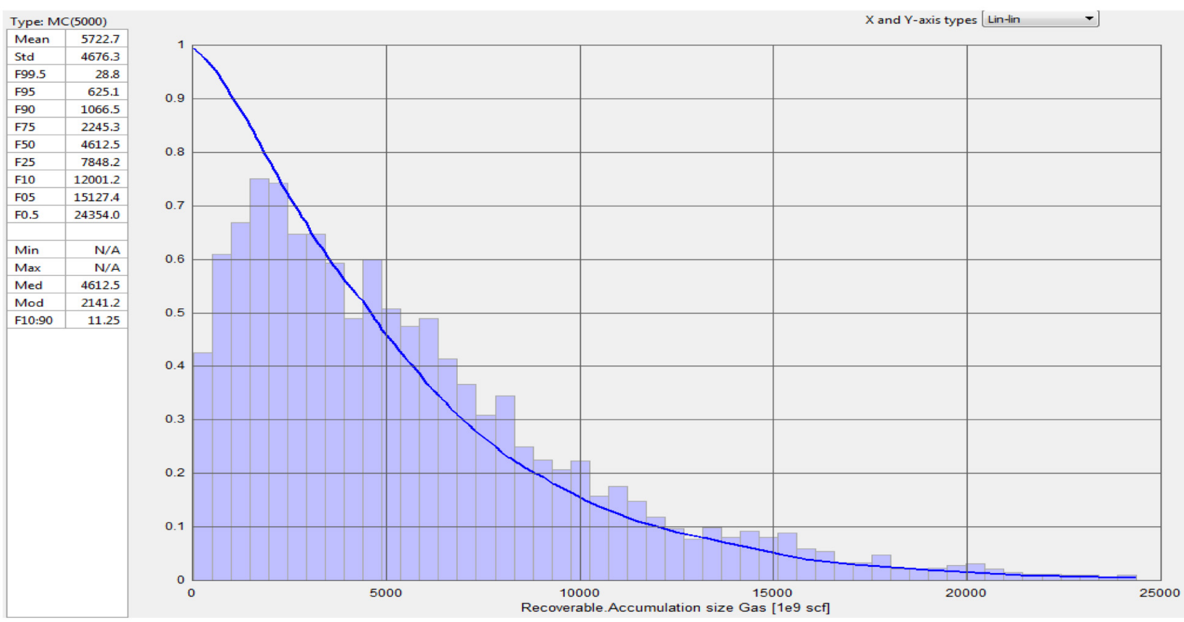

Figure 5—Computed Recoverable Resource Distribution

Exploration Prospect Value Assessment

The second pillar in the solution is the exploration prospect value assessment. The estimation of cost answers a key question in value assessment – what economic benefits will be received by the existing or potential owner of the license taking into account as possibilities the opening of a field and profitable sale of its production, the opportunity to lose money on a dry well or on the appraisal wells when a commercial opening is not confirmed.

An important aspect of the value assessment is a determination of the project timeline and associated activity model with estimated uncertainties. This includes uncertainties on costs & duration of exploration and exploitation activities while honoring both sub-surface and surface facility constraints and dependencies. Activities cover the entire project life cycle from exploration through pilot, development and production to abandonment as illustrated in Fig. 6 below. Each activity can have uncertain durations, costs, capacities and performance while scheduling can be constrained by targets and outcomes of earlier activities.

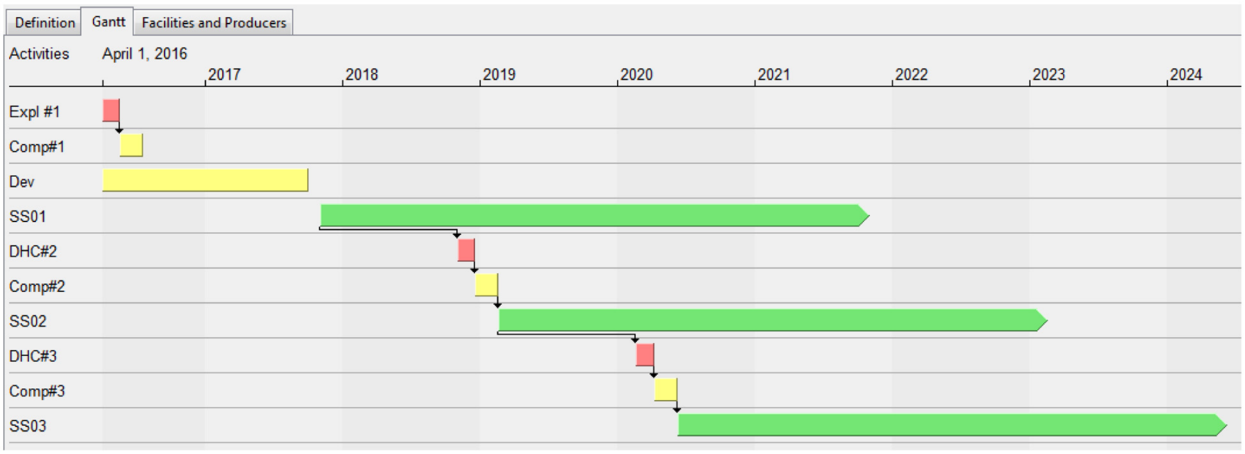

Figure 6—Activity Gantt View

Once the geological and activity models are completed, the fiscal terms for the regime are defined and put into an economic model. At this point, the inputs are fed into a Monte Carlo simulation which can be run to understand the range of hydrocarbons and economic cash flows that can be expected from the project as seen in Fig. 7 below.

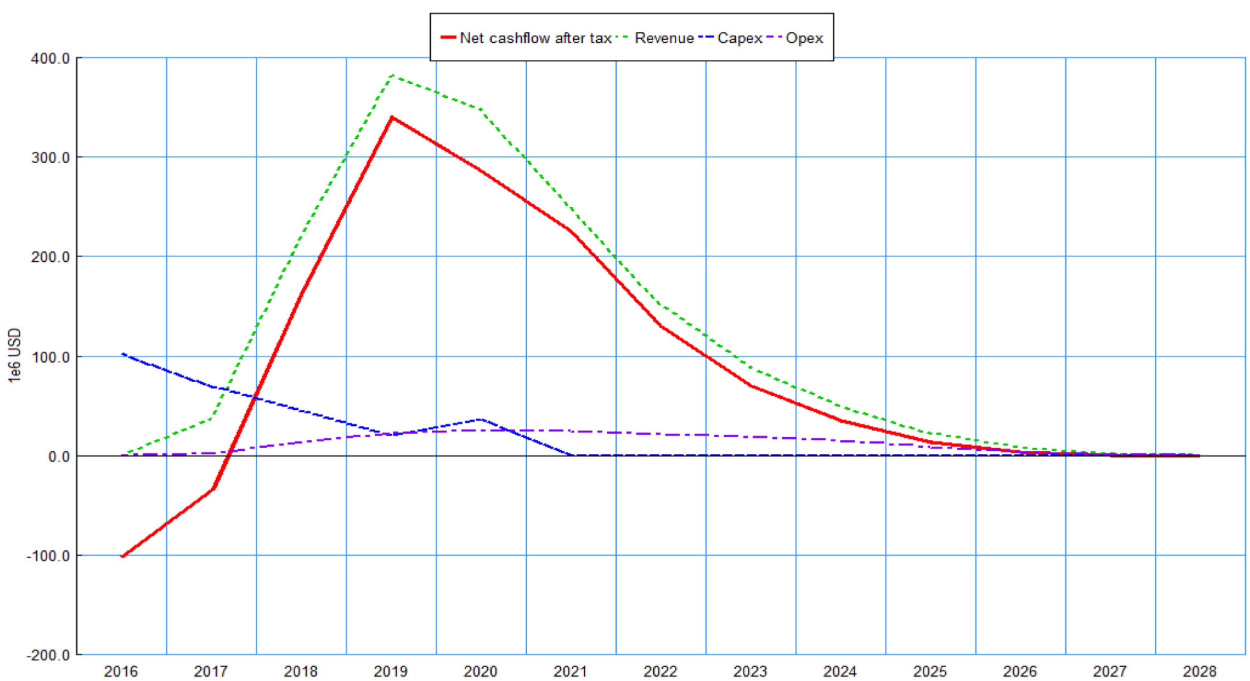

Figure 7—Economic Cash Flow, Revenue, Costs and Capital

Exploration Portfolio Optimization

The third pillar in the solution is the optimization of the exploration portfolio. Portfolio optimization provides a mechanism for the organization to establish a vision and show different paths of achieving these desired goals and objectives (Reinsvold et al. 2008). It allows companies to make a step change from being reactive to being proactive to rapidly changing market and industry realities.

The application of portfolio optimization techniques can greatly increase the efficiency of the planning process by focusing on the interactions between projects and their effect on total business performance. These portfolios and their component projects can then be analyzed in the context of meeting both strict long term strategic goals and short term operational targets (Back and Guercio 2010).

However, the one of the key differences in this solution is the consistent propagation of risk and uncertainty from the subsurface to the commercial evaluation and the ability to aggregate Monte Carlo samples for each individual project into a stochastic representation of the entire portfolio. The other is the ability to model uncertainties, including correlations and dependencies, both within an exploration prospect and between exploration prospects, as constraints in the optimization while ensuring that all these constraints were honored while optimizing the value of the portfolio.

Commercial software is available to use multiple optimization algorithms to determine the optimal selection of projects in the portfolio in terms of percent working interest participation and start year for the investment (Back and Kirk 2012). In the graphic in Fig. 8 below, the mean value of the optimum portfolio is shown in red, the mean time series goal targets in green and the probability of meeting each goal in blue. The objective of the optimization was to maximize the mean value of discounted after tax net present value for the entire portfolio, while adhering to project dependencies and meeting minimum annual mean targets over the next eight to ten years for the mean value of before tax cash flow and gas revenue and within maximum targets for the mean value of exploration capital investment and operating costs.

Figure 8—Portfolio Goal Performance

The trade-off between different metrics is also a critical part of the analysis which includes efficient frontier type portfolio combinations (simultaneously maximizing value and minimizing risk metrics) and rapid sensitivities on key parameters such as price, operational restrictions, and scheduling delays (Back and Kirk 2012). The portfolio optimization exercise feeds into the exploration planning effort and is used to analyze multiple portfolios and their performance against goals and key metrics such as production, cash flow, reserve additions, and finding and development costs.

Case Study

A sample set of forty exploration opportunities was assessed in a single opportunity catalog from prospect subsurface risk assessment all the way through to economic evaluation and portfolio optimization to demonstrate the proposed solution. The first step was to create a reservoir model for each prospect to determine ranges for key reservoir parameters such as hydrocarbon gas oil ratio and recovery factor as shown in Fig. 9 below as well petro physical parameters such as porosity and gas saturation. Correlations were set up for certain reservoirs between both formation oil volume factor and gas oil ratio and oil saturation and porosity.

Setup | Input parameters | Descriptive parameters

Parameter [Units]	Dist. type	Mean	Std. dev.	F90	F50	F10
Gas oil ratio [Sm3/Sm3]	Unif	842.0	97.0	707.6	842.0	976.4
Recovery factor Oil [decimal]	Unif	0.35	0.0289	0.31	0.35	0.39
Recovery factor Assoc. Gas [decim...	Unif	0.35	0.0289	0.31	0.35	0.39

Figure 9—Petro physical Parameters for Reservoir Model

A Monte Carlo simulation was run to determine the range of uncertainty in recoverable hydrocarbon resources by each phase as shown in Fig. 10 below.

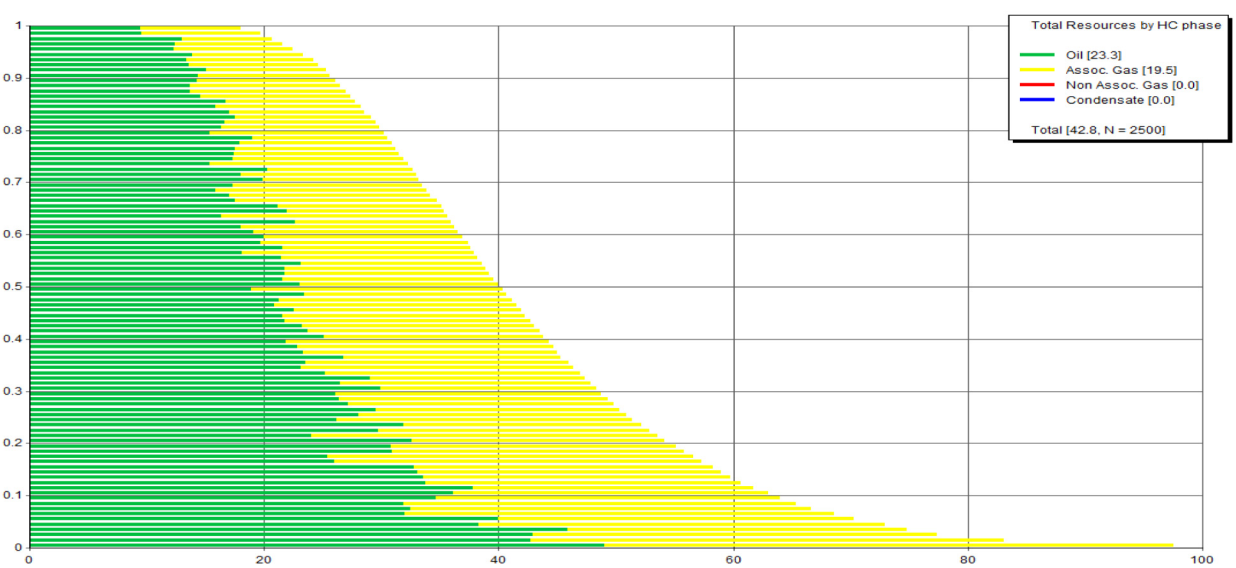

Figure 10—Total Recoverable Resources Distribution by Phase

The second step was to input ranges on key full cycle activities, dependencies and costs from each relevant stage - pre-exploration and exploration to exploitation. This included seismic, initial exploration well, additional wells required for pilot production, infrastructure development (if pilot is successful), full development drilling. These activities considered alternative entry, acquisition and possible development strategies for each prospect. A fiscal regime was defined and assigned to each exploration project in the opportunity catalog and the economic evaluation was then completed.

A decision tree output of results was computed using a Monte Carlo simulation for each evaluation. The discrete outcomes for each branch of the resulting tree were saved with associated probabilities of occurrence and time series arrays of cash flows, capital, operating costs and revenues for each exploration opportunity shown below in Fig. 11 below.

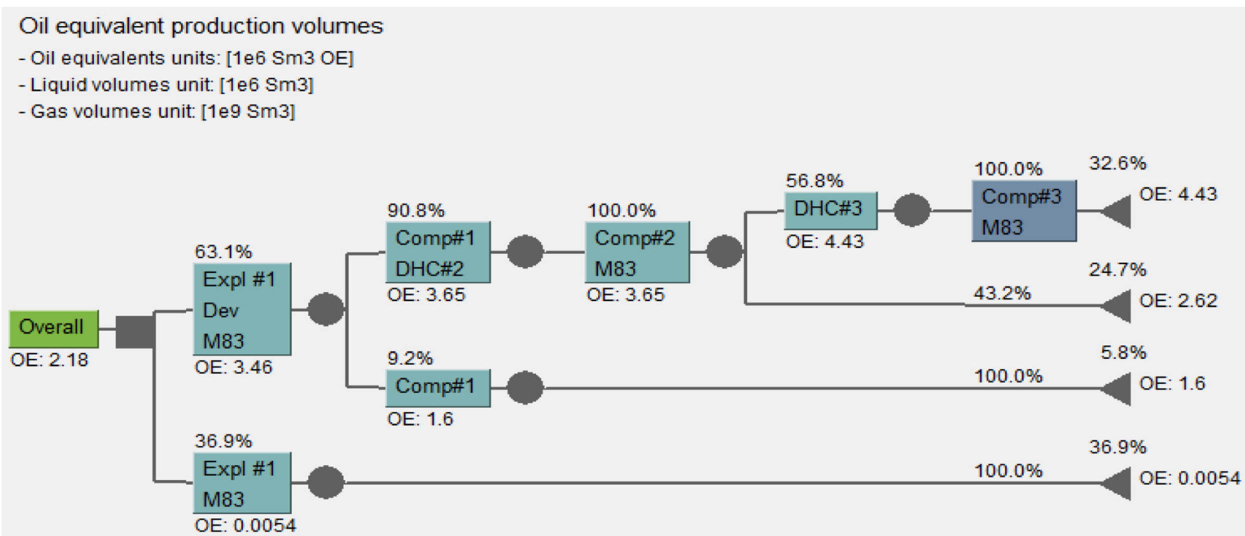

Figure 11—Decision Tree Outcomes and Associated Probabilities for an Exploration Prospect

The third step in the solution was to bring each of the forty exploration potential investments into the single shared opportunity catalog and drive the portfolio optimization exercise. A portfolio model was created to define participation and scheduling dependencies between exploration projects and drive both short term and long term corporate goals. The key targets were to increase the mean value of cash flow and revenue while keeping the mean value of capital investment and operating costs flat over the next ten years. Multiple optimized portfolios were generated using a simple rank and cut on a single value metric, a linear program balancing multiple goals and project dependency constraints and a genetic algorithm optimizing the portfolio on a nonlinear metric while still meeting each defined goal and project dependency. The simplest approach using a rank and cut methodology was not able to compute a single portfolio that met all defined goals and constraints. However, the linear program optimizer was able to consistently outperform the basic rank and cut while meeting all defined goals and constraints in the portfolio model and maximizing multiple value and minimizing multiple risk metrics along the efficient frontier as seen in Fig. 12 below. The genetic algorithm was also able to generate multiple alternative portfolios that met all defined goals and constraints while maximizing and minimizing a non-linear stochastic measure.

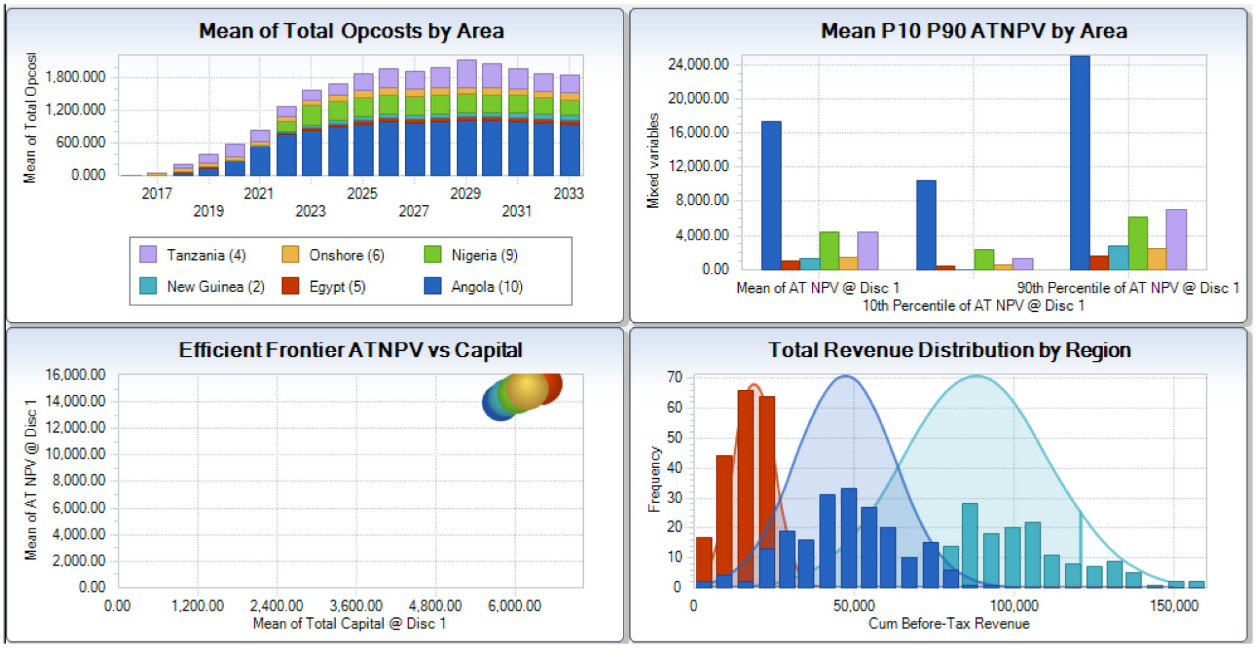

Figure 12—Dashboard of Multiple Efficient Portfolios and Comparison of Key Indicators across Regions and Areas

Results and Observations

In the petroleum industry's constantly changing environment, planners must have access to high quality information to make quick, well-informed decisions. An integrated national petroleum company deployed this solution within their exploration teams and realized important business benefits. The key benefits observed after deployment of this integrated solution were:

- Optimized portfolio observed increased revenue with decreased risk and costs
- Improved data quality and understanding of risk
- Consistent uncertainty evaluation from prospect to portfolio
- Increased shared understanding and confidence in results
- Strategic corporate goals balanced with operational constraints

This national petroleum company has seen improvement in their ability to quickly prioritize projects based on their contribution to key company metrics. The different optimization techniques with the new solution in place allowed for quick generation of alternatives and comparison between multiple portfolio investment options at different trade-offs between value and risk. The following graphic in Fig. 13 below illustrates the comparison of multiple portfolios along the value vs risk efficient frontier (defined here as the Mean vs Semi mean deviation of NPV) computed by commercially available portfolio optimization software.

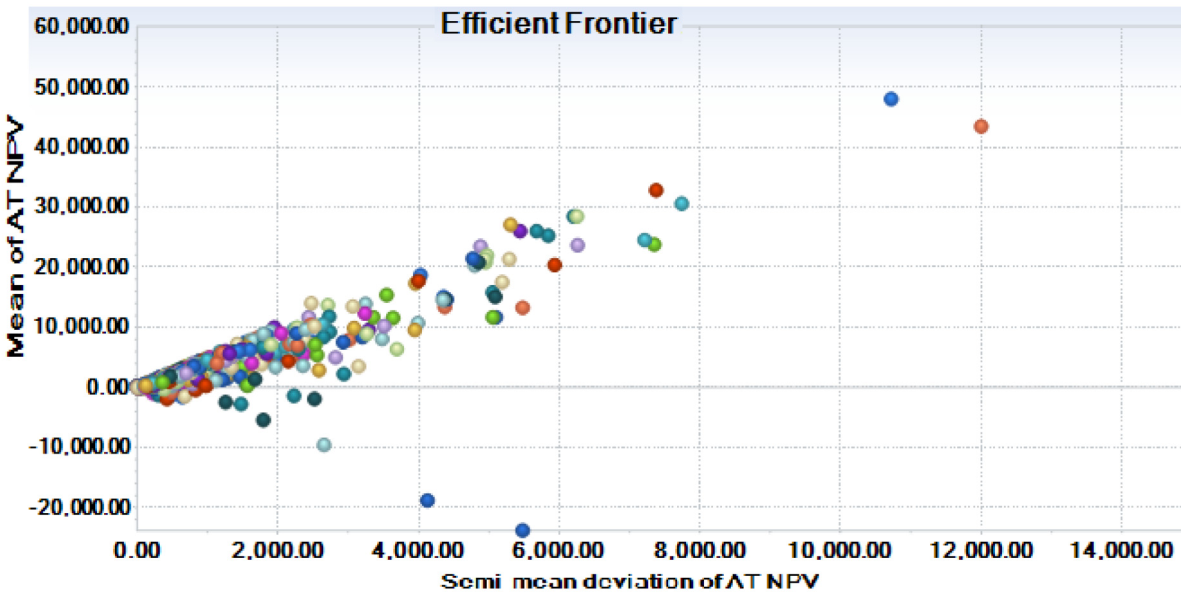

Figure 13—Multiple Portfolio Comparison of Efficient Frontier Value and Risk Indicators

This solution provided the ability to view and assess the exploration opportunities, run different scenarios and determine the appropriate course of action to create optimum value with the least amount of risk for the organization. It provided a quick and consistent stochastic aggregation from prospects through to an optimized exploration portfolio. Historically, it would have taken weeks to isolate, gather and structure key data, and require multiple asset engineers and analysts to stop their value-added work to assist in the effort. With data being entered once in a central repository, the data quality improved and consequently so did the confidence in the investment portfolio. Key decision-makers were able to react more quickly to new information and test the sensitivity of different portfolios to changing business environments.

As a result of this approach, a more thorough understanding and mitigation of key risks and uncertainties affecting the success of exploration opportunities was demonstrated amongst the exploration teams. The new solution increased the transparency of decision-making in exploration and improved the capability of teams to learn from history and better understand how to replicate success. This solution allowed the exploration planning function to better balance strategic exploration goals with asset level constraints (i.e. drilling rigs, equipment) (Back and Guercio 2010).

Conclusion

This paper has outlined a proposed solution for optimized exploration planning consisting of three key pillars. The first pillar detailed the exploration prospect risk assessment including the capture of key geologic and petro physical parameters and computed estimates of ranges of recoverable resources for each exploration opportunity. The second pillar covered the value assessment of each exploration prospect which required an estimation of costs and associated activities for each prospect while taking into consideration dependencies, drilling resources, and other constraints. The third pillar outlined the optimization of the portfolio of exploration assets to allow the company to balance the risk and uncertainty with the distribution of value for the portfolio and align short term operational goals with the strategic direction for the future.

This proposed solution for optimized exploration planning improved efficiencies in the exploration decision making process and management of an exploration portfolio. The consistent approach in the integrated solution directly linked key risks and uncertainties in the subsurface properties of the reservoir and related activities all the way through to the commercial evaluation of each exploration opportunity and a stochastic aggregation of the optimized portfolio. The key solution benefits included shortening the capital allocation and portfolio optimization cycle, faster decision making, higher quality of the investment portfolio to reflect both acceptable value and risk, improved collaboration and confidence in the results to drive more strategic resource planning.

A national oil company deployed this solution and found that this integrated exploration planning approach led to significantly improved overall exploration portfolio revenue at reduced risk and cost. This solution provided the ability to visualize and assess the exploration opportunities in a single repository, quickly run different business scenarios and determine the appropriate course of action to create optimum portfolio value with the least amount of risk for the organization.

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