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A Probabilistic Approach to Shale Gas Economics

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Abstract

Unconventional resource plays, and shale gas plays in particular, are generally characterized by lower geologic risk and higher commercial risk. Large, continuous accumulations of tight, often naturally-fractured shale serve as both a hydrocarbon source and a potentially-productive reservoir. The likelihood of commercial production is a primary uncertainty in these plays, resolved in part by drilling pilot (appraisal) wells. The need to understand the range of potential for commercial realization places a heavy burden on the economic evaluation process. This requires maximum insight into the basis for a decision to pursue or not pursue any particular shale gas resource play. Beyond this, a consistent approach to economic evaluation is of critical importance when comparing the economics of various plays. Without consistency, comparison of multiple shale gas plays becomes extremely difficult, if not impossible.

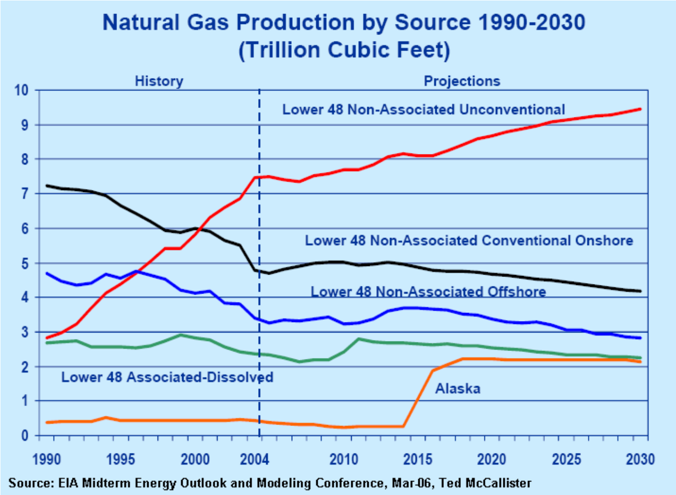
The ability to define and represent key uncertainties and understand their respective impacts on economic feasibility is vital to play entry and subsequent decisions involving continued investment. Issues such as well design (vertical, horizontal, multi-lateral, etc.), well performance (initial production rates, estimated ultimate recovery, etc.), stimulation technologies, commodity price environments, as well as commercial aspects such as acreage availability and cost, project execution timing, and rig count are critical. Furthermore, because there are few well-established commercial plays, analogs are constructed mainly from these data-bearing plays; e.g. Fort Worth Barnett, and applied to emerging or prospective plays. Uncertainty surrounding the technical or commercial fit of a given analog for new basins/plays must be accounted for in the play/project evaluation process.

Pioneer focused on a number of domestic shale plays that differ in many ways, most notably in terms of "the stage of commercial maturation." Due to the large number of unknowns, deterministic economic modeling gave the team a low confidence in the results and was viewed as merely a scoping indication of commercial potential. It was recognized by the team and by management that deterministic, single-point solutions are unable to provide a reality check for the input assumptions, which typically leads to overly optimistic results. Therefore, it was determined that these models, while good for quick scoping evaluations, would be inappropriate for decision-making in emerging plays. A better solution had to be found.

This paper describes a consistent, systematic process employed in the evaluation of a number of shale gas plays, how various software applications were deployed, the vital role of multi-disciplinary participation, iterative modeling efforts and conclusions. In a general sense, we believe the lessons learned here can be applied either to unconventional or conventional upstream oil and gas projects.

Introduction

Production from unconventional resource plays is expected to increase over the next decade. As the various plays are commercialized, unconventional gas will gain an ever-increasing share of total U.S. gas production. Gas production from unconventional plays; e.g. tight sands, shale, coal bed methane, etc., are poised to support mid-term natural gas supply growth and help offset declines in production from more conventional sources (Figure 1).



Source: EIA Midterm Energy Outlook and Modeling Conference, Mar-06, Ted McCallister

(Figure 1, continued next page)

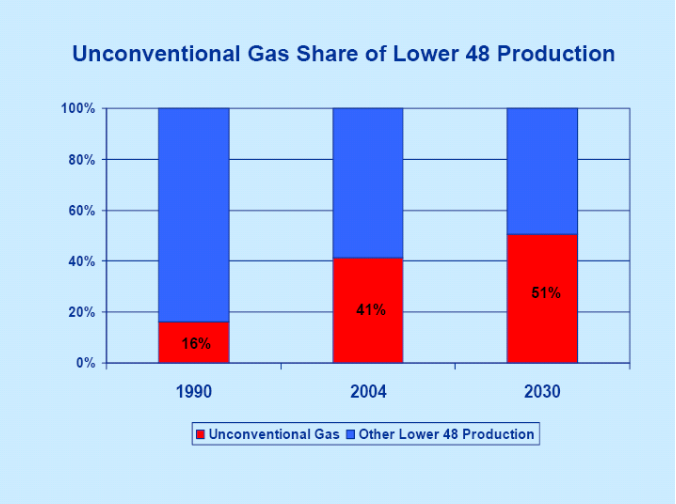


Figure 1: EIA Annual Energy Outlook 2006

Unconventional resource plays are not new to Pioneer. With the acquisition of Evergreen Resources, Inc. in 2004, the company gained coal bed methane expertise and has sought to continue its diversification into unconventional opportunities. That having been said, the probabilistic approach described herein had not been previously deployed as a key analysis process. In 2005, a team was formed and chartered to evaluate a number of plays across North America, including several shale gas opportunities. Preliminary geologic work led to the selection of a subset of plays that justified additional technical/commercial focus. The challenge facing the company was then to identify those plays from the subset that were most strategically-aligned with the company's stated growth objectives and could warrant further investment. In early 2006, a multi-discipline business development team was assigned the task of evaluating both individually and comparatively a group of seven to ten shale gas plays across North America. The objective was to forge a clear vision of the respective contributions in areas such as reserve replacement, risk diversification, production growth, and the potential to achieve F&D cost targets. An additional key underlying goal was to create corporate expertise in new core areas. It was quickly apparent that traditional economic evaluation tools were not going to provide the answers the team was seeking. In the words of Haskett and Brown (2005) "The valuation and assessment of unconventional or 'continuous resource' opportunities is not feasible using traditional probabilistic volumetric-based methods. A fully stochastic business, value-chain model is the best way to assess the potential of an unconventional play. Such an evaluation method allows for multi-disciplinary and cost input that affords decision makers with the appropriate data to make good decisions."

A key challenge arose given the substantially different stages of maturation for each of the basins/plays; e.g. commercially-established areas to emerging or prospective basins where very little or no performance data was available. While each opportunity required individual characterization, it would be necessary to logically and consistently evaluate all of the plays together as a potential portfolio.

Discerning key uncertainties, preparing for key decisions

As stated previously, the geologic risk (in terms of hydrocarbon accumulation presence) associated with unconventional resource plays is considered low from a classic dry hole perspective. Structural and stratigraphic complexities, such as faults, absence of top and bottom seals, etc., however, remain a concern given that well count (scalability) and well design/performance can be severely affected by these elements and in turn can play a key role in play entry/execution decisions. Once this hurdle is overcome, attention shifts to anticipated initial production rates, estimated ultimate recovery per well (EUR), rig scheduling, drilling and completion costs and stimulation requirements. As stated above, many assumptions are often derived from the commercially-established Fort Worth Barnett shale play due to a lack of shale gas analogs in emerging areas.

A spreadsheet-based deterministic economic model was utilized in the early evaluation stages to characterize the opportunities and begin to understand the impact of uncertainties through single point sensitivity analysis. However, a purely deterministic approach is limited in capturing the full impact of the high number of interdependencies characteristic of a shale gas resource play. Pioneer realized this and attempted to update its deterministic model, similar to other authors in the past, by incorporating the probabilistic input into a spreadsheet. For example, Hooper (2001) presented a probabilistic prospect evaluation with spreadsheets that had been utilized by Anadarko. Although this method had some applicability for us, we determined that there were more technically advanced, commercially available products that could perform this analysis more effectively.

In addition to selecting the appropriate evaluation tools, it was important to get acceptance of the process from individuals within the company, "the human factor." Thanks to Pioneer's previous exploration endeavors, the company already had a good understanding of risk and uncertainty. Our geoscientists and engineers have been implementing formal risk and uncertainty representations in conventional exploration and exploitation project characterizations for a number of years. The strategic planning group implemented a risk and uncertainty-based portfolio optimization tool a few years ago. Management has thus become increasingly comfortable with project results represented in terms of ranges of outcomes and associated probabilities.

Building from previous exposure to uncertainty and probability methods within the organization was particularly important because the transition from a deterministic to a stochastic mind-set does not happen overnight. While some were familiar with the probabilistic approach, others were more comfortable with a deterministic approach and wary of the "black box" reputation of probabilistic software tools. Early in the evaluation process, specific steps had to be taken to increase the comfort level for all participants. This generally involved an iterative process of patiently working with the software, restoring iterations, making needed changes; e.g. applying correlations between inputs and critiquing the results for realism. The model output also needed to be presented to "client teams"; e.g. budget and planning, who required the results in a fit-for-purpose format. Furthermore, both the technical input and associated results had to be understood by other asset-driven "client teams" external to the core business development group to ensure full agreement and commitment to the analysis outcomes.

A second key factor in the general acceptance of a fully stochastic/probabilistic approach was "push back" from management to deterministically-derived results from earlier project screening efforts. Management was not comfortable with a single point solution and with not knowing how optimistic or pessimistic results might be. It was imperative that the team be able to provide logical and well-thought-through answers to the following questions:

- What is the probability of achieving our key profitability metrics?
- What is the probability of breakeven at a given price?
- What is the maximum exposure?

These questions could only be answered by quantifying a number of specific uncertainties, which could not be accomplished without a methodology change.

After considering several stochastic spreadsheet models as well as industry accepted economic software packages, PetroVR® from Caesar Systems was selected as the primary tool for integration and construction of planning models, based on the following attributes:

- Project-driven input logic which lends itself to multi-discipline collaboration; e.g. each shale play could be modeled from the reservoir to the sales point
- Flexibility in building distributions around any input variable in the model
- Ease of documentation and restorability of data input
- In-house expertise and product availability

While we recognized that the deterministic spreadsheet model might have been modified to allow for a more probabilistically-driven approach, the time and effort required would have been considerable and would arguably have resulted in a tool that would have essentially "mirrored" what we had via the chosen probabilistic planning tool.

Methodology

Figure 2 shows the steps required to build the models. The following discussion describes the process in detail.

Define objectives. The first step in the process was to define overall objectives for the project. Management needed to make informed decisions regarding prudent levels of investments in multiple shale gas plays. The team was tasked to evaluate multiple plays while adhering to the following evaluation premise:

- The analysis had to be consistent across all plays so that the multiple plays could be aggregated into a portfolio view.
- The maturation stage of each play was unique and this had to be taken into consideration as part of the analysis process.
- All critical uncertainties had to be captured and defined; each play had to be treated as a unique pilot/development project with a unique execution plan.
- The integrated evaluation process required an integrated evaluation tool that could adapt to varying stages of play technical and commercial maturity.
- The plays selected for analysis would ultimately need to be "rolled-up" into a portfolio of opportunities.
- An informative range of outcomes that properly represented technical/commercial exposure and associated probabilities had to be generated.
- Buy-in had to be obtained from divisions/core teams external to the core BD group.
- A comprehensive, yet concise, management presentation was required that would allow them to make informed decisions as to expenditure levels warranted for the various plays.

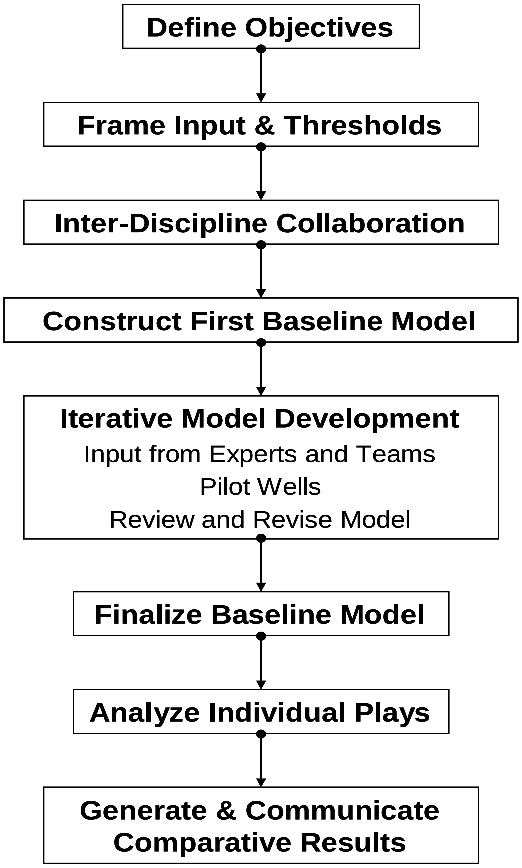


Figure 2: Process Diagram

Frame input and thresholds. Each model was built following a uniform logic to maintain consistency. A standard template (see Appendix) was developed and distributed to the external teams as a way to document assumptions and capture ranges of uncertainty around key variables. Ownership in the model and results by all concerned parties was achieved because the overall technical/commercial evaluation was a highly interactive and communicative process.

Inter-discipline collaboration. As noted above, the technical input and direct involvement of all key disciplines is essential throughout the planning cycle, specifically reservoir engineering, drilling, completions, operations, geology and to some extent marketing.

Early in the process, representatives from asset teams were brought together for joint planning sessions. (It is worth noting that quick turnaround of each iteration in the model building cycle is critical to keeping the multi-disciplined team involved and participating.) Open and active communications and collaboration led to growing confidence in the process and increasing buy-in among all contributors.

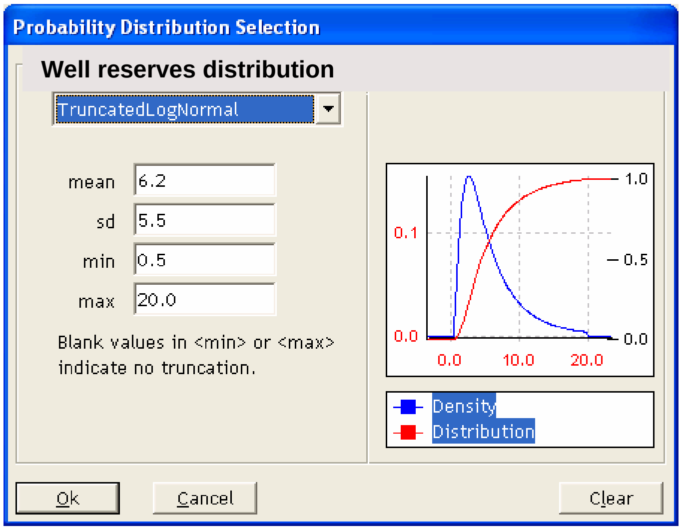
Building the baseline models

Prior to seeking final input from the business development team, external core teams and specialist disciplines, it was necessary to build a first-generation (strawman) model. These models were constructed for each play using known reservoir and well data and were the starting point for the process.

The first-generation model input and results were then discussed with the "client teams" and technical specialists and refined. This led to the development of a second-generation model, the results of which were once again transmitted to client teams.

The third-generation (and final) models were those that received final approval from the client teams and/or were subject to one last round of edits prior to advancing to the roll-up stage.

The models were built from the reservoir up. Gas-in-place estimations for each basin under evaluation were derived from data known for that specific area or from established plays, such as Fort Worth Barnett. Lognormal distributions were defined to capture the upside and downside volumes. Similar estimations were implemented for recovery factor with an associated lognormal distribution. These parameters, combined with the existing or proposed gross acreage position, would result in the range of reserves to be recovered from the project. The gross acreage and resulting well counts were factored down (risked), accounting for subsurface anomalies; e.g. karsted or faulted areas, as well as surface limitations where either were known or believed to exist. The established or proposed well spacing then defined the maximum number of locations to be drilled in the area.

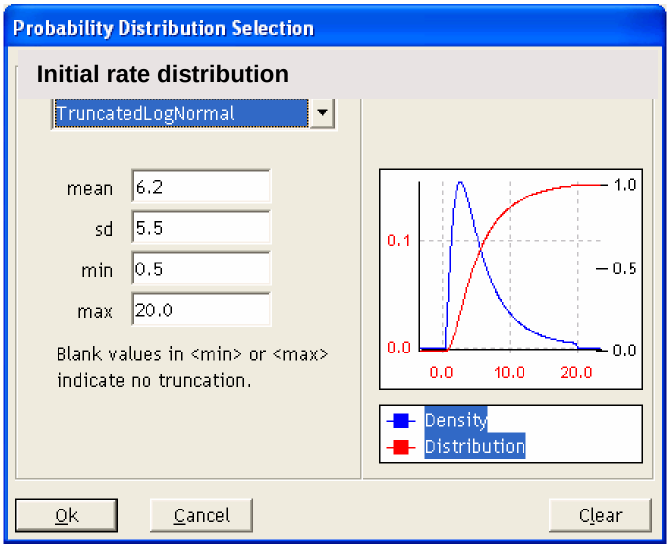

Probability Distribution Selection

Well reserves distribution

TruncatedLogNormal

mean 6.2
sd 5.5
min 0.5
max 20.0

Blank values in <min> or <max> indicate no truncation.


Probability Distribution Selection

Initial rate distribution

TruncatedLogNormal

mean 6.2
sd 5.5
min 0.5
max 20.0

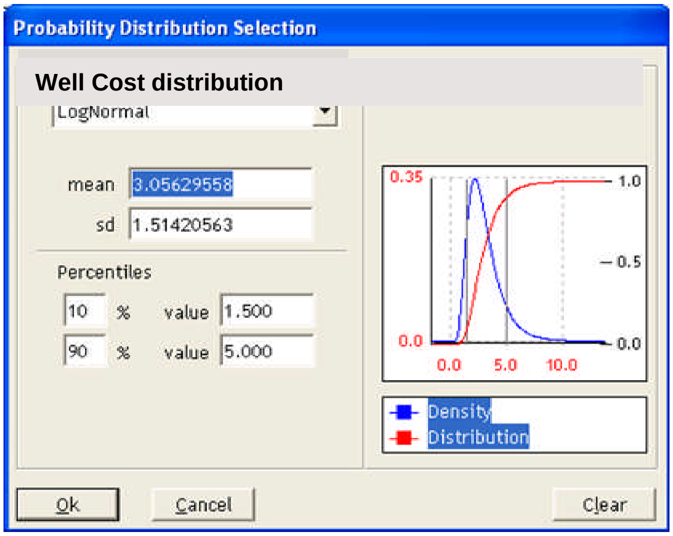
Blank values in <min> or <max> indicate no truncation.

Figure 3: Data Input, EUR and IP Distributions

Type well models were developed based on analogs, where available, or as a derivation of average Fort Worth Barnett shale gas well performance. EUR and initial production (IP) were correlated based on historical data. IP and EUR are obviously two of the key parameters that define commerciality in a play. Truncated lognormal distributions were defined for these parameters to capture the full range of uncertainty (Figure 3). Expected production decline rates also play a key role in commerciality assessment. The well performance curve was calculated and normalized in a spreadsheet prior to importing it into the model.

One very influential parameter in the economics of statistical plays is well cost. Because these projects are drilling and completions cost intensive, building a learning curve to reduce cost and drilling/completions time is fundamental. The stochastic models allowed us to define cost and days to drill and complete ranges, as well as a linear learning curve to model cost savings (Figure 4).

The existing link between PetroVR® and Peep® was utilized in order to take advantage of the customized company fiscal models. This had the disadvantage of not being able to capture uncertainty in fiscal or financial parameters.

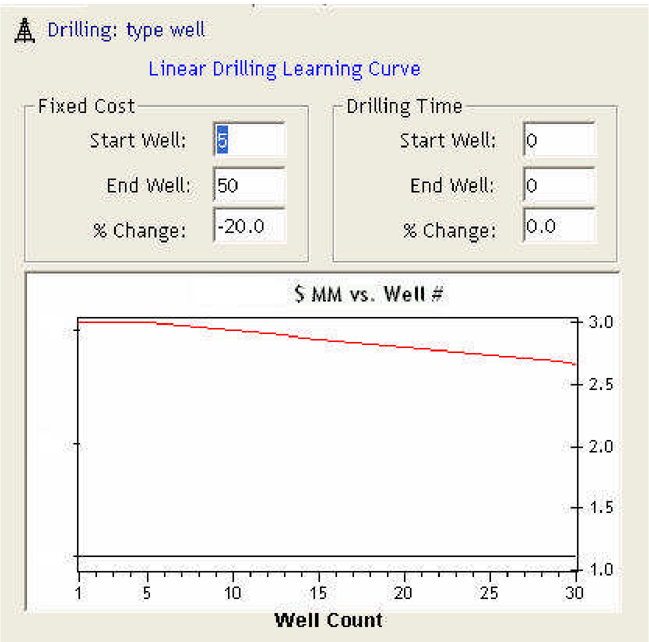

Probability Distribution Selection

Well Cost distribution

LogNormal

mean 3.05629558
sd 1.51420563

Percentiles
10 % value 1.500
90 % value 5.000



Drilling: type well

Linear Drilling Learning Curve

Fixed Cost

Start Well: 5

End Well: 50

% Change: -20.0

Drilling Time

Start Well: 0

End Well: 0

% Change: 0.0

Figure 4: Data Input; Cost Distribution and applied learning curve

Iterative model development

The initial models did not include built-in pilot wells. The plan was to build the full range of go-forward cases and then roll up the risk with a decision tree. After consultations with the client teams, it was determined that the pilot decisions needed to be built into the economic outcomes. In order to minimize exposure, multiple decision points were introduced in the form of a two-stage pilot program. Go—No-Go decisions were modeled at the end of each program, based on defined thresholds for IP and EUR.

In addition, correlations were defined where necessary; e.g. IP vs. EUR, Well cost vs. EUR, etc. These correlations were honored for Monte Carlo sampling/simulation, as indicated below in Figure 5.

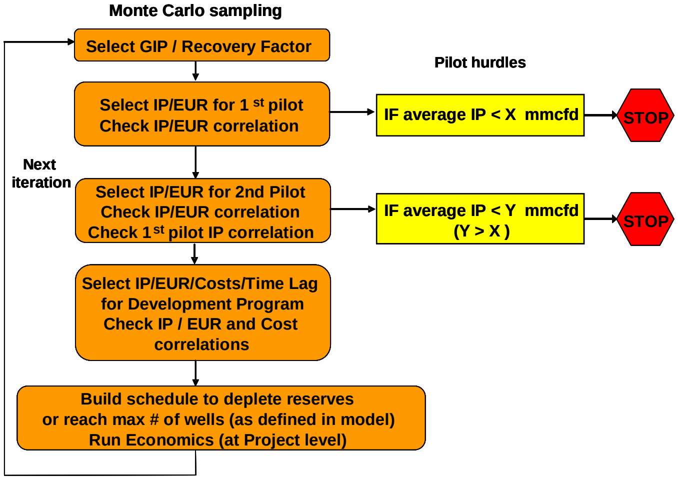


Figure 5: Flow diagram for Monte Carlo sampling

When the model is solved probabilistically, a combination of gas-in-place volume and recovery factor is selected from the individual distributions, thus defining the total reserves for that iteration. An IP/EUR pair is also selected from the distributions and the correlations are validated. If honored, the first pilot program will be drilled and at the end, a Go—No-Go decision is made based on the pilot results. The same process occurs for the second pilot program. If successful, the business simulation software application will proceed to the development phase, where it will drill wells until the project reserves are depleted or until the maximum number of locations defined are drilled based on acreage and spacing.

Pilot wells

Each play was modeled independently, generating distributions for all the key metrics necessary to evaluate the projects individually.

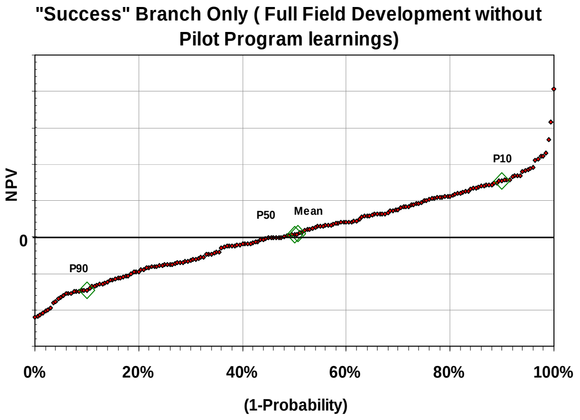


Figure 6a: NPV distribution for full field development

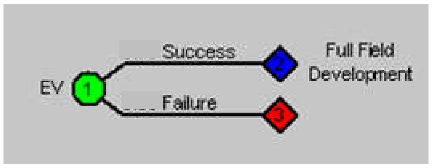


Figure 6b: Full field development decision tree excluding pilot program

The first pass of the model showed a number of outcomes with negative NPV that indicated uneconomic wells being drilled (Figure 6a). In unconventional plays, generally every well drilled is completed (except for mechanical failures). Unlike the concept of a conventional "dry hole" on a decision tree (Figure 6b), the failure leg for a continuous resource play is defined not by dry holes but rather by uneconomic wells, which in turn can vastly increase production cost uncertainty. PetroVR® allowed the flexibility to build this key realization into the business simulation model. The modeling process time was significantly reduced because of automatic scheduling by the planning tool according to the input assumptions.

Figure 7a indicates that approximately 70 percent of the outcomes would result in the project being dropped after the pilot phases. The probability of commercial success is approximately 30 percent. By introducing pilot programs and thresholds that must be met for the project to move on to development (Figure 7b), we were able to minimize the downside.

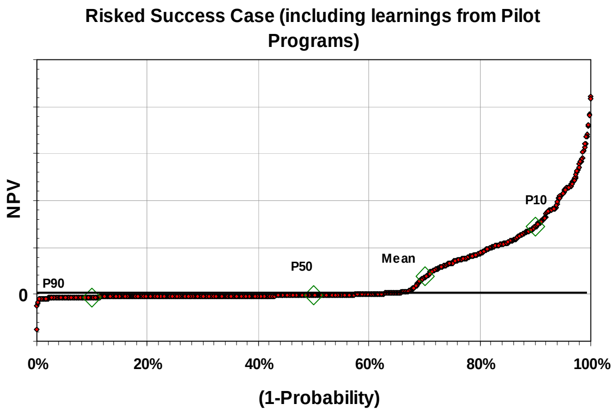


Figure 7a: NPV distribution for full field development including pilot program

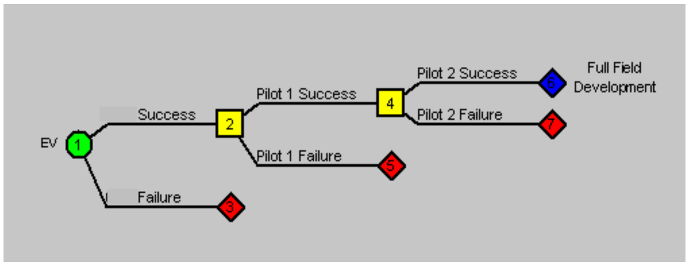


Figure 7b: Full field development decision tree including pilot program

Individual Play Results

To analyze and validate the Monte Carlo-derived results, and the input correlations on certain input variables, the data was imported into an Excel spreadsheet where several cross-plot graphs were populated. An example of one cross-plot is shown in Figure 8.

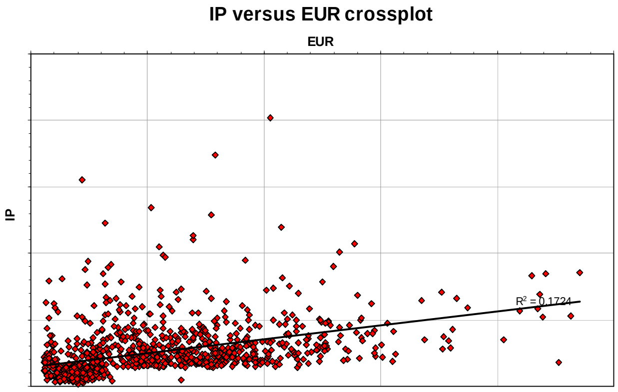


Figure 8: Cross plot IP and EUR

Breakeven probability and Net Present Value distribution displays. The overall chance for an individual play to break even at a given price and the maximum total exposure added significant value to the entire evaluation process is illustrated in Figure 9.

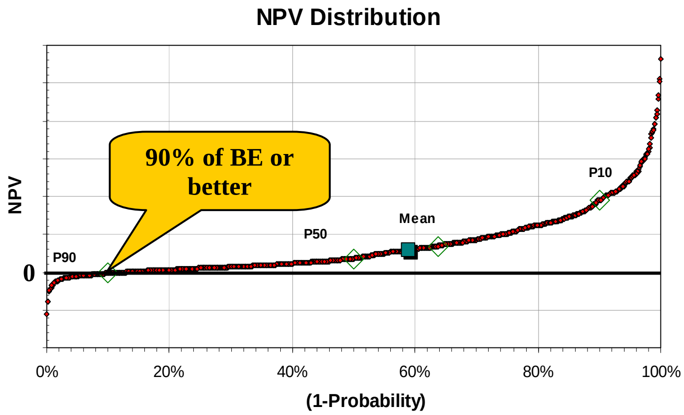


Figure 9: Distribution of NPV outcomes indicating the probability of break even

Another useful feature of the business simulation software is that all results from the Monte Carlo processes are stored and the runs can be accessed individually. Each iteration can be restored and analyzed in detail. A Gantt chart is presented in Figure 10 showing the schedule of activities that occurred during a particular iteration.

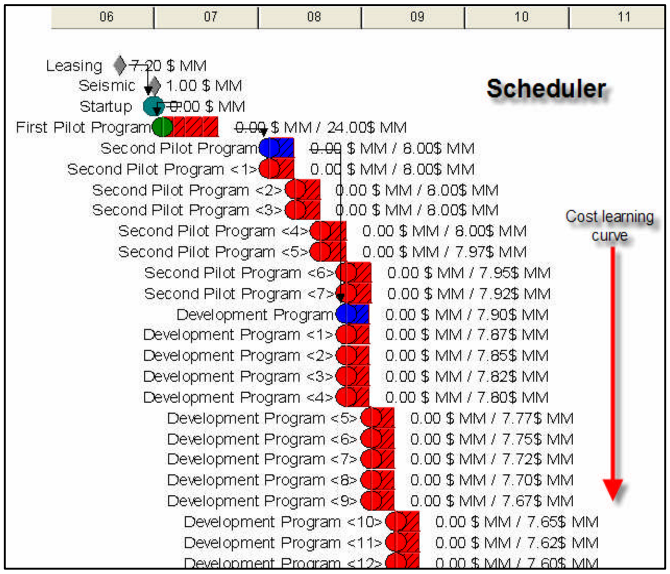


Figure 10: Schedule of activities

This is particularly useful in troubleshooting errors or problems and gaining insights around dependencies. This helped to gain confidence in the tool and lessen the "black box" perception often derived from probabilistic modeling software.

Aggregate Portfolio Results

Once the individual play/project models were completed and validated, they were aggregated to generate metrics corresponding to the entire portfolio of plays. Having dedicated considerable time and effort to generate ranges of outcomes for the individual projects, it only made sense to aggregate them probabilistically (as opposed to adding the mean cases). It was necessary to create a relatively simple model in

Crystal Ball® to capture the key metrics that were going to be used to represent the overall project and to generate the corresponding distribution of the portfolio of plays. Figure 11 provides an example of graphs that were built to represent the probabilistically rolled-up play outcomes.

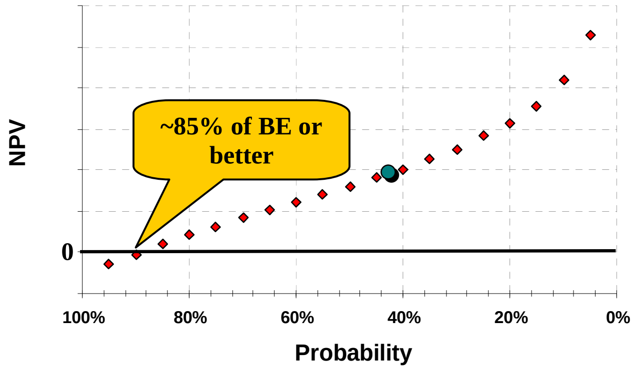


Figure 11: Distribution of NPV outcomes indicating the probability of break even for consolidated portfolio

Production and cash flow projections could not be aggregated probabilistically. Instead, we represented the most relevant time-series adding mean cases (Figure 12).

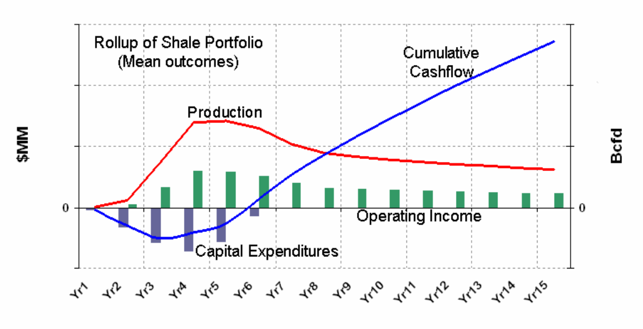


Figure 12: Production and Cash Flow projections

Finally, the multiple plays considered were comparatively characterized in terms of value and associated uncertainty. As shown below in Figure 13, certain plays promise a higher probability of breakeven but limited upside. Using deterministic analysis would likely have yielded little differentiation in the decision criteria used to select among plays. Play "A" compared to Play "D" is a clear example where probabilistic analysis leads to a different conclusion by providing highly visual, better quality results. Both plays have a similar Mean NPV, but Play A has a much higher probability of achieving success.

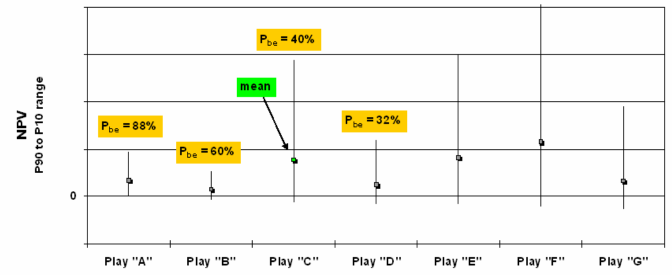


Figure 13: Portfolio view

Conclusions

Impact on decision-making

- The impact of resource play pilot wells can be quantified in an effort to facilitate investment decisions, including "pilots of convenience." These insights could not have been provided by deterministic analysis.
- Much of the uncertainty inherent in these plays could not have been properly quantified and clearly conveyed to management via deterministic analysis and decision-making would have therefore suffered.
- A key objective in any project development is cost optimization. The process undertaken herein enabled the determination of which cost factors had the most influence in project economics and helped focus our execution efforts from an operational perspective.
- Using business simulation software to help create consistency across each individual asset analysis facilitated comparative analysis.
- By linking the decision process to the probability associated with key decision metrics, management is better positioned to make informed investment decisions.
- Individual and program breakeven points at a given commodity price as well as maximum exposure for the program provide the necessary input for management to evaluate risk tolerance.
- Single-point, deterministic model optimistic bias became obvious when compared against the distribution of outcomes generated via the process undertaken herein. This effect is amplified when a portfolio is being evaluated.
- This approach to probabilistic analysis, if systematically applied to the evaluation of a conventional play, would likely lead to a different display of the uncertainties and indicate different decisions than those derived from strictly deterministic analyses.

Human Factors

- Demystified the "black box" perception that complex probabilistic tools possess. All the results from Monte Carlo sampling are stored and can be individually restored; therefore, any counterintuitive results can be verified and troubleshooting becomes rather easy.
- A product champion is necessary for use of this probabilistic business simulation software; someone with good knowledge of the application plus a good understanding of all disciplines involved in the evaluation.
- The integrated business simulation approach attracted knowledge experts from client teams; buy-in was obtained and the quality of insights provided for decision making was improved significantly.
- A future benefit will be to evergreen the business simulation models with actual data in order to perform post action reviews and gain additional learning to improve decision quality.
- Modeling tool provided the useful frame for multi-discipline cooperation; final model has buy-in from different groups which makes results more reliable in the eyes of management.

Acknowledgements

The authors acknowledge the efforts of our many associates in the preparation of this paper and thank the management of Pioneer Natural Resources USA, Inc. for the opportunity to devote our time and efforts to this paper for the benefit of industry success in new, unconventional resource plays.

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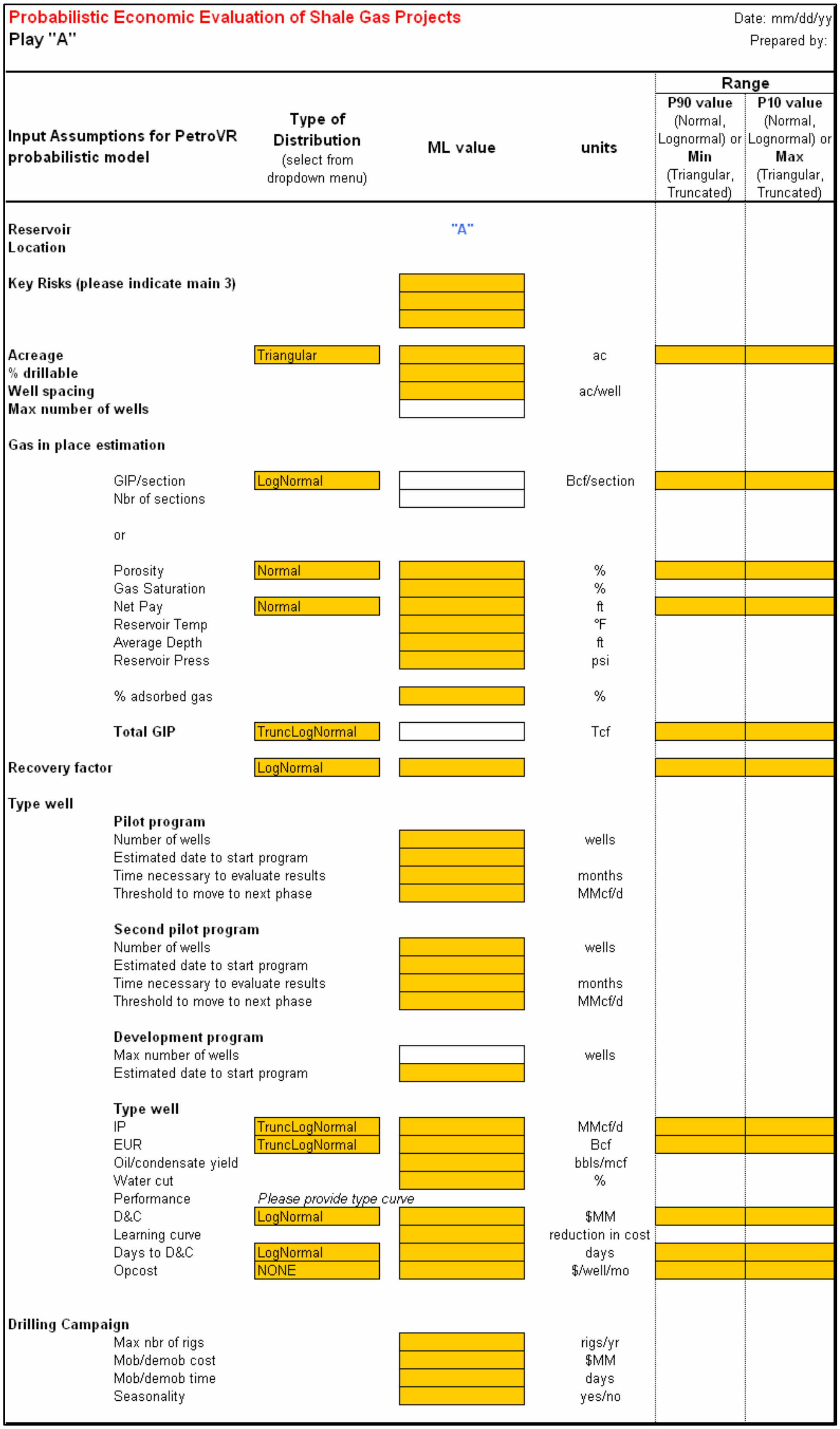
Appendix

Template for collecting Inputs from teams



Probabilistic Economic Evaluation of Shale Gas Projects

Play "A"

Date: mm/dd/yy

Prepared by:

Input Assumptions for PetroVR probabilistic model		**Type of Distribution** (select from dropdown menu)	**ML value**	**units**	**Range**	
					P90 value (Normal, Lognormal) or **Min** (Triangular, Truncated)	**P10 value** (Normal, Lognormal) or **Max** (Triangular, Truncated)
Reservoir			"A"			
Location						
Key Risks (please indicate main 3)						
Acreage		Triangular		ac		
% drillable						
Well spacing				ac/well		
Max number of wells						
Gas in place estimation						
	GIP/section	LogNormal		Bcf/section		
	Nbr of sections					
	or					
	Porosity	Normal		%		
	Gas Saturation			%		
	Net Pay	Normal		ft		
	Reservoir Temp			°F		
	Average Depth			ft		
	Reservoir Press			psi		
	% adsorbed gas			%		
	Total GIP	TruncLogNormal		Tcf		
Recovery factor		LogNormal				
Type well						
	Pilot program					
	Number of wells			wells		
	Estimated date to start program					
	Time necessary to evaluate results			months		
	Threshold to move to next phase			MMcf/d		
	Second pilot program					
	Number of wells			wells		
	Estimated date to start program					
	Time necessary to evaluate results			months		
	Threshold to move to next phase			MMcf/d		
	Development program					
	Max number of wells			wells		
	Estimated date to start program					
	Type well					
	IP	TruncLogNormal		MMcf/d		
	EUR	TruncLogNormal		Bcf		
	Oil/condensate yield			bbls/mcf		
	Water cut			%		
	Performance	*Please provide type curve*				
	D&C	LogNormal		$MM		
	Learning curve			reduction in cost		
	Days to D&C	LogNormal		days		
	Opcost	NONE		$/well/mo		
Drilling Campaign						
	Max nbr of rigs			rigs/yr		
	Mob/demob cost			$MM		
	Mob/demob time			days		
	Seasonality			yes/no		

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