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Optimal Appraisal Well Location Through Efficient Uncertainty Reduction And Value Of Information Techniques

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Abstract

Successful exploration, efficient appraisal, and profitable extraction are the three phases of any E&P project; each in turn is dependent upon the prior. However, efficient appraisal of newly discovered resources sets the stage for maximizing project profitability and managing risk. The goal of an efficient appraisal program is to achieve maximum reduction in uncertainty with minimal cost. The more certain a company is regarding the size and scope of a particular project, the better decision it can make on its development case selection, the greater the possibilities for downside risk mitigation, and the more efficiently it can manage its entire development portfolio. The end of the appraisal period occurs when further uncertainty reduction would not materially effect the principle development decisions, or at the point at which the downside project risk becomes acceptable to the company.

Specific appraisal locations should typically be selected on their ability to provide the greatest overall reduction in project uncertainty. Project uncertainty is tied directly to the variance of the outcome distribution and can be summarized by the uncertainty range, which utilizes the commonly understood distribution descriptors. An understanding of the difference between discrete learning events and population sampling learning is critical to the estimation of uncertainty reduction.

Potential appraisal locations will contribute to a reduction in uncertainty given either failure or success. Competing appraisal locations may be compared through their propensity for uncertainty reduction using standard value of information techniques (VoI). This quantitative method provides an assessment of the relative value of uncertainty reduction of competing or prioritized development locations, and may be extended within a multi-prospect situation to rank competing prospects within a commonly constrained business opportunity.

Introduction

The post-discovery appraisal effort abounds with opportunity for efficiency. Optimal choices for appraisal well locations and knowing when to end the appraisal phase of a project will not only create the maximum value for the organization, but will provide the most efficient path to proved resource.

Demirmen (1996, 2001) has pointed out the opportunity for the use of value-of-information techniques to rank preference amongst appraisal opportunities. He also points out that under or over-appraisal erodes economic value. This author agrees and extends the argument to a decision context for both single and multiple prospect objectives.

One of the most difficult dilemmas faced by appraisal personnel is where to locate the next well. Teams are frequently dry-hole phobic stating that the project "can't afford to have a dry appraisal well". A frequent result of this approach is a virtual twinning of the existing discovery, or minimal step-out, which provides little if any reduction in uncertainty and necessitates further drilling to determine materiality. Security of activity has taken precedence over security of business.

Appraisal activities must be distinguished from exploration and development activities. Appraisal has its own set of rules and objectives. In order to appraise there first needs to be a successful exploration effort. Exploration "success" is the establishment of a minimum quantity of producible resource. It is the acknowledgement that sufficient resource is present and deemed producible that would tempt a responsible owner to proceed with further appraisal or development. As such the basic risk elements of container (reservoir, vertical seal, and lateral seal) and contents (source, timing, and migration) are present. Exploration risk is no longer of concern, but size uncertainty abounds. Successful exploration creates uncertainty. Appraisal activities reduce uncertainty as a primary objective. Development activities, though still contributing to uncertainty reduction, have a primary responsibility for commercial extraction and management.

Often the priority at hand is to "prove reserves". Yet, safe, reserve-proving, minimal step-outs form existing locations only offer a circuitous, and therefore inefficient paths for the adjustment of our state-of-knowledge to the state-of-nature. True efficiency results from the acceptance of optimal appraisal risk such that the state-of-nature is rapidly approached.

The objective of appraisal activities is therefore the assessment of materiality, and not the proving of resource. Efficient reserve addition is a by-product of efficient materiality assessment.

Appraisal activities are performed in the context of decisions to be made. If an activity does not potentially alter a decision, or is not anticipated to provide positive value through the learning it achieves, then it should not be undertaken. The assessment of value should be calculated through standard value of information methods as documented by several authors over the past several years (Coopersmith et al 2002, Head 1998, Konix 2000)

Appraisal activities typically revolve around the following questions:

1. Is the project worthy of development?

2. What is the appropriate facility size for the production potential through time?

3. What is the optimal development and production strategy required in order to achieve peak financial success?

4. What is the extent and probability of downside risk that can be identified and potentially mitigated?

Assessment of materiality is the determination of the state-of-nature and economic viability. It is the reduction of uncertainty within the context of decision-making, all the while realizing that we are hampered by our inability to obtain full information.

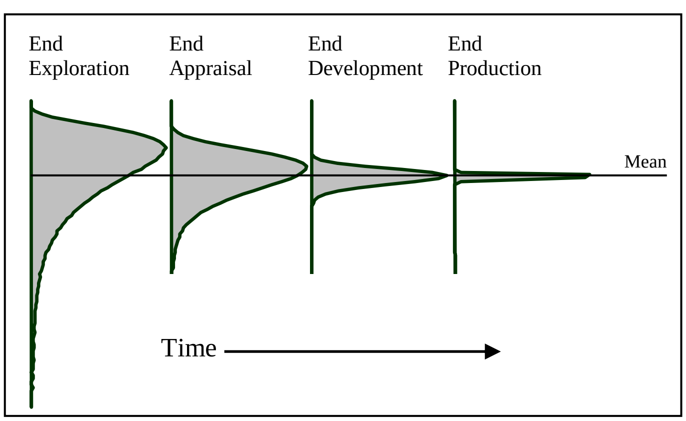

Figure 1: Uncertainty distribution narrows through time

Uncertainty through time

Ultimately, all producible hydrocarbon resources in a prospect will be proven. Unfortunately, absolute certainty must wait until the end of the project's producing life. Until that time we are striving to reduce the uncertainty. The most rapid reduction of uncertainty usually occurs within the initial few appraisal wells

Figure 1 shows a decreasing distribution range through time. The outcome is most uncertain; the variance is largest immediately after exploration success has been established. We know something is there, we just don't know how much. All activities after that point should contribute in some way to the decrease in uncertainty. As the state-of-knowledge approaches the state-of-nature, variance, a statistical measure of the diversity of outcome potential, is reduced.

Though Figure 1 is seen in many corporate risk and uncertainty manuals and training courses, there is an element that often leads the less experienced professionals astray. The mean of the distributions stays constant through time. Though this is possible, the probability that the mean is constant through time is negligible. The message is that uncertainty narrows through time. The mean should be changing, as is shown in one realization in figure 2. Step changes should be expected especially if there are discrete learning events.

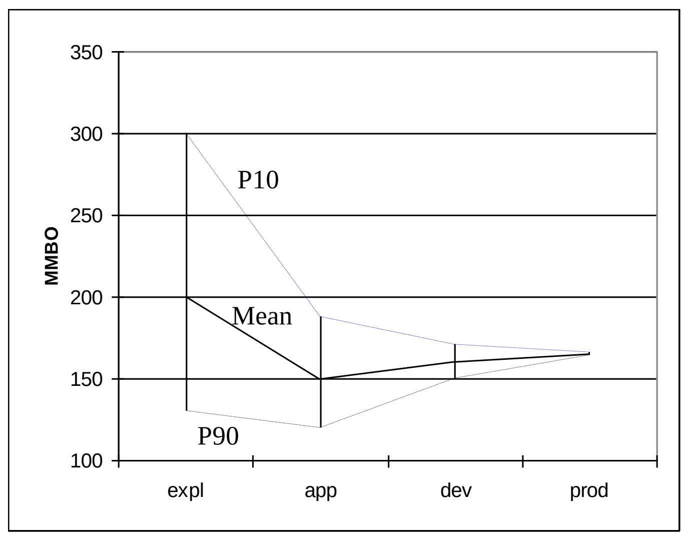

Figure 2: Uncertainty reduction with mean revision through time (single realization)

After exploration success has been determined, well information is gathered to revise pre-drill inputs. Given that the initial well in a new field is seldom if ever representative of the mean, team members should be cautioned about over reliance on initial data. Initial post drill estimates of uncertainty are the result of the reservoir extent and reservoir character uncertainties as interpreted by the project team. Estimates are derived from all available information. Each uncertainty is assessed by range, the endpoints managed for validity, and then all uncertainties are combined to create the total distribution. This is the starting point for appraisal activities.

Discrete Learning vs. Population Sampling

Materiality assessment is accomplished through uncertainty reduction based on learning. There are two types of learning: "Discrete Learning" and "Population Sampling". Every appraisal activity will provide one if not both types.

Discrete learning results from the assessment of mutually exclusive, distinct events or discovery possibilities. Reservoir extent is the prime example. The productive reservoir section either is, or is not present at a particular appraisal location. Given that the section is present, then a new uncertainty distribution for the field will reflect that finding. The new distribution will be a step change from the initial distribution and usually be significantly different from the distribution that would be created given absence of the productive reservoir section.

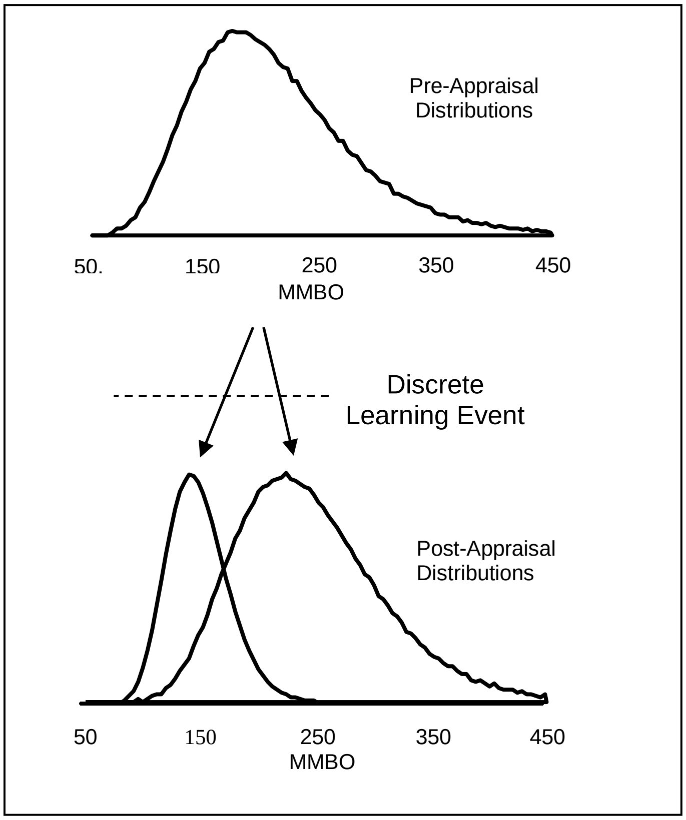

Figure 3: Discrete Learning events create multiple output distributions (distributions shown as frequency plots).

The distributions that are created through discrete learning events must be mutually exclusive and totally exhaustive. In other words, it is possible to tell which distribution exists on outcome and all possible outcomes will have been covered. As such, the risked means of the two child distributions must sum to be equal to the mean of the parent. Similarly, the risked variance of the two child distributions will sum to equal the variance of the parent. Both the mean and the variance are additive and sum based on the risk factoring of their individual probabilities of occurrence.

This summation logic is inescapable and provides an excellent point for validity checking of the individual components. If the sums do not tally for the distribution set, one or more of the following problems must exist:

1. One or more distributions must be incorrect,
2. The probabilities of occurrence of the child distributions are incorrect, or
3. The starting point distribution is incorrect.

Given that Appraisal teams are usually better at describing distributions for discrete outcomes than they are at mentally manipulating and combining multiple distributions, it is preferable that the teams start with the discrete outcomes and roll back to the pre-appraisal distribution mechanically. Do not expect the sum of two lognormal outcome distributions to roll-up to a lognormal initial distribution. Occasionally the discrete outcome distributions are not available or are not yet recognized to be present. Then the team derived pre-appraisal distribution is the best available and should be used.

Discrete learning events are directly related to interpreted alternatives. They follow earth models, depositional models, and hypotheses. They require divergent paths in interpretation and the recognition of mutually exclusive solutions.

When the learning is not from discrete learning events, when the solution falls on a continuum that is not predictable by any discrete model, when the ultimate uncertainty reduction stems solely from repeated tests, we are learning through population sampling.

Population sampling learning occurs in the absence of directed or hypothesis based appraisal. It involves the acceptance of the pre-appraisal distribution and acknowledges that any and all future data points will merely adjust the uncertainty range of the component without changing the overall hypothesis.

For example, porosity is typically population sampling based. Without a model governing discrete learning (such as a diagenetic model) that would cause step differences in outcome, any test within the field boundary provides an equal amount of information as any other test. The reserves assessment calculation uses average porosity (field or pool) as one of the inputs. Average field porosity validation requires a large number of data points. The number of data points is proportional to the size of the field. As we drill more appraisal wells, and eventually development wells we have an increasing handle on the distribution of porosity.

There are limits to uncertainty reduction through population sampling. Capital stewardship (economic viability and acceptable, profit-oriented business practice) prevents us from drilling an excessive number of wells to identify the "exact" average porosity. As such, when the efficient number of wells is reached in field exploitation, porosity uncertainty remains. This leftover variance is "irreducible uncertainty".

Justification of Appraisal Location

Choosing an appraisal well location is easy. Justifying it is more difficult.

The re-drill of existing, valid data locations will not give either discrete or population learning. Population sampling learning is virtually independent of location. Any new data point provides a reduction in uncertainty. As such, population learning may be treated as a constant in the assessment of alternate appraisal locations, and therefore population sampling should not be used to justify specific appraisal locations. In and of themselves, population sampling based desires must be combined with other objectives such as discrete learning events or efficient development well positioning. The latter will involve more intense economic justification while the former will typically precede economic based go/no go decisions and be involved more intimately with facility sizing and downside risk mitigation.

There will always be learning from population sampling, but as the number of wells increase, the incremental learning from each new well decreases. That being said, a broad sampling of the reservoir is more likely to encounter spatial variance of reservoir parameters than a concentrated grouping of wells. Population sampling outcomes with the well density available during appraisal remains unpredictable and lacks a predictive model.

Discrete learning follows models or hypotheses so the learning that is to be achieved by a particular well is a function of its location with respect to the locations already drilled. This fact allows discrete learning objectives, in the context of risk and economics, to justify appraisal well locations.

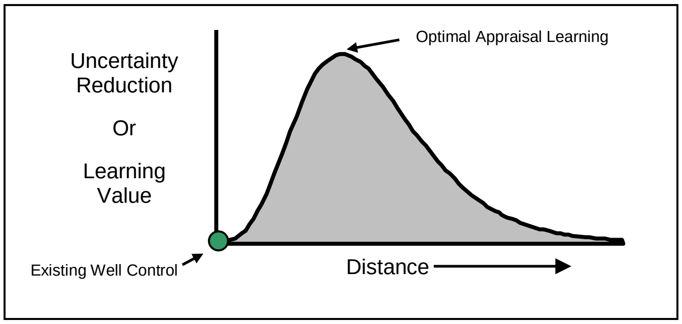

Figure 4: Value of learning is directly related to the distance from existing information, and is equivalent to uncertainty reduction.

As the distance between the potential appraisal location and the existing well control increases (figure 4), the ability to reduce field size uncertainty initially increases. It reaches a maximum after which the dry-hole risk associated with the location and the portion of the original distribution left uninvestigated combine to make the location less efficient.

To the right of the optimal peak the appraisal well, if successful will provide abundant information, however the probability of it being successful is decreasing rapidly with increasing distance from control.

Figure 5 shows two potential appraisal locations. Both locations have a discrete learning objective of establishing materiality through area uncertainty reduction. Location A is a moderate distance step-out from the discovery well while location B is testing the far end of the area distribution. Each well will contribute to the reduction of uncertainty. The preferred well will have the greatest decrease.

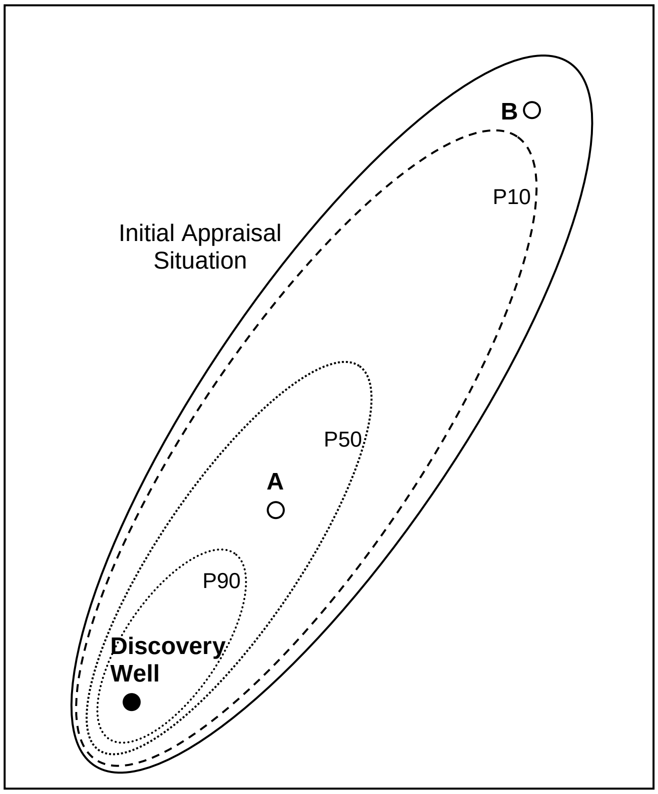

Figure 5: Map showing initial discovery and P10-P50-P90 estimates of reservoir extent based on the working model of the evaluation team.

For this example assume that the only discrete learning that can be done is the extent of the productive reservoir. For each well there are two outcomes and therefore four outcome distributions in total. Each well may either find or not find reservoir. Location A provides moderate uncertainty reduction in given success or failure (Figure 6).

Location B provides an excellent, but very low probability of uncertainty reduction given success, and virtually no uncertainty reduction given failure (Figure 7). The shown probabilities of success are based on the initial reservoir extent model. When the probabilities are taken into account location A offers a far higher chance of uncertainty reduction while location B leaves uncertainty virtually unchanged.

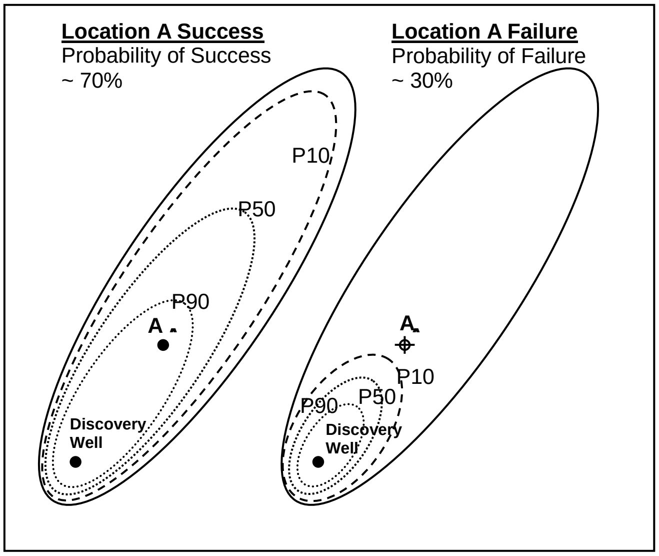

Figure 6: Mapped distributions of reservoir extent given the drilling of location A.

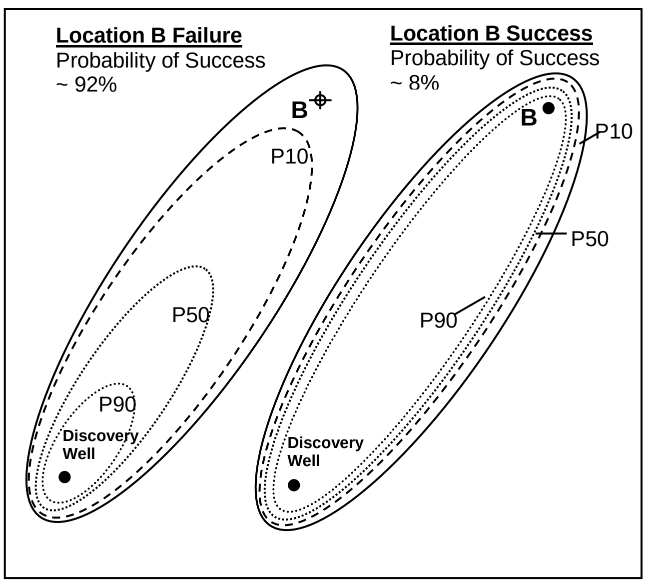

Figure 7: Mapped distributions of reservoir extent given the drilling of location B.

It should be immediately apparent that the twinning, or near twinning of the discovery well, though virtually certain to succeed in the discovery of reservoir, produces little if any reduction in overall field uncertainty. Minor step-outs from an existing location that mostly duplicate existing information will have little or no effect on forward decisions and result in further capital expenditure that may not be warranted.

Quantification of the uncertainty reduction by any action may be tracked by the risked sum of the variance. The quantitatively preferred location will be the one that contributes, on a risked basis, the greatest decrease in field uncertainty. Note that there may be several discrete learning objectives of the appraisal program. The number of discrete outcome distributions will be equal to 2^n where n = the number of learning objectives, assuming that each objective only has two outcome distributions. Typically though, individual appraisal wells have limited learning objectives.

The Tie to an Economic Threshold

Location A is preferred over B as it is more likely to provide a risked decrease in the distribution variance. The drilling of the example's location B would likely (92%) require the drilling of additional appraisal well(s) to determine materiality, <u>unless</u> location B was set to test the minimum acceptable resource limit (or "critical reserves"). The preferred appraisal location will be the minimum distance from existing control that will provide maximum reduction of <u>reserves</u> uncertainty (as opposed to resource uncertainty). Standard risk and uncertainty based economics (preferably stochastic) must always be carried out on the initial distribution to assess the viability of drilling any appraisal wells. Economics continues to be superimposed over uncertainty management. Appraisal wells should be positioned to confirm critical reserves at the earliest opportunity.

Location A

		Probability of Failure 30%	Probability of Success 70%
	Initial Distribution	Appraisal Failure	Appraisal Success
P10	300	188	330
P50	200	150	245
P90	130	120	170
	(MMBO)		

Initial 10-90 Range	170
Expected Final 10-90 Range	132
Uncertainty Reduction %	**22%**

Location B

		Probability of Failure 92%	Probability of Success 8%
	Initial Distribution	Appraisal Failure	Appraisal Success
P10	300	290	330
P50	200	190	310
P90	130	125	290
	(MMBO)		

Initial 10-90 Range	170
Expected Final 10-90 Range	155
Uncertainty Reduction %	**9%**

Figure 8: Calculation of expected uncertainty reduction percent.

Measuring Uncertainty Reduction

Variance reduction is independent of the mean of the resulting distributions. The ideal situation would have all team members fully statistics literate and be readily able to calculate variance. This ideal state is rare.

Within a single field appraisal context, all appraisal options attempt to reduce uncertainty from a fixed starting point… the initial distribution. Given that the initial distribution is exhaustive (all possible outcomes are included), the change in variance produced by the individual outcome distributions will be directly proportional to the decrease in the range from P10 to P90. Figure 8 shows the A and B locations calculated for percent uncertainty reduction.

Ultimately, for any field, the reduction of uncertainty becomes map-able, though for all practical purposes teams would likely be well served by calculating their proposed appraisal wells and then testing to see if any other locations were logical, feasible, and provided higher learning.

This calculation set may also be shown in standard tree form as shown in Figure 9.

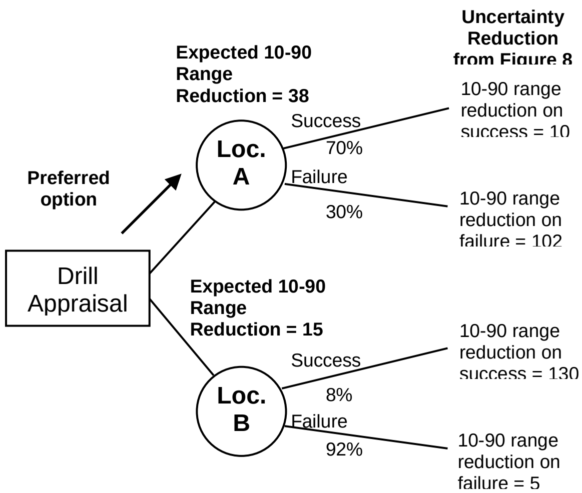

Figure 9: Tree format for uncertainty reduction comparison.

Is it possible to increase variance through appraisal drilling? It has yet to be proven, but it is a logical assumption that appraisal wells add to knowledge and that any addition to knowledge should increase certainty, which is a decrease in variance. It is assumed that the initial distribution is correct and that it is the sum of any and all discrete outcome distributions. It is conceivable then that an individual outcome distribution may indeed have higher variance than the initial distribution, as other discrete outcomes may have greatly narrower variance. It is at least difficult to find a practical earthscience based model that adequately demonstrates this occurrence without invoking errors of omission in the construction of the initial distribution.

Mistaken initial distributions are temporary. Increased variance due to unanticipated factors will reset the initial distribution as opposed to leave it in an error state.

The primary task for appraisal wells is to efficiently move our state-of-knowledge towards the state-of-nature. The efficient placement of wells to reduce uncertainty is the fastest, lowest cost method (assuming all well locations are approximately equal in cost) to obtain greater certainty on the actual size of the discovery. The rapid elimination of sub-economic fields or the reduction of downside risk for facilities sizing with expeditious tie-in maximizes the value to the company. As a by-product, efficient appraisal well location (based on the efficient learning concepts described above) produces the most efficient path for recognition of proven reserves.

The avoidance of risk for the sake of proving “some” reserves is detrimental to the long-term interest of the company. The selection of well location based solely on surety of reserve delineation is not justified. Conversely, the requirement for appraisal wells to prove reserves may lead to lower rates of return and delayed elimination of sub-economic assets. The assignment of reserves “to be proven” by an appraisal location begs the response, “if we knew how many reserves the appraisal well would prove up, we wouldn’t need to drill the well”. Appraisal wells do prove up reserves, when successful, as do all wells that are economic and prudently drilled, however they remain our first and foremost weapon to reduce uncertainty, and that is their priority.

The Transition from Appraisal to Development

As more efficient appraisal wells are drilled into a prospect, the less education an additional appraisal well is expected to provide. The diminishing knowledge return of appraisal wells must be taken into account in a decision context. As appraisal continues, it will be increasingly important for appraisal locations to be adjusted to accommodate efficient development. It may be better to pay for a portion of development with slightly encumbered uncertainty reduction during the latter stages of appraisal. This is yet another opportunity for a value-of-information evaluation.

The economic viability of the field must be monitored and assessed after every appraisal well or significant learning event (discrete or population sampling). Materiality is assessed in two contexts, first as mentioned, is economic viability; second is the context of the decisions contingent to the drilling.

Will the potential learning from a further appraisal well be worth the cost? Efficient location methods for appraisal options must precede and be used in standard VoI techniques in order to justify the appraisal well as opposed to commence development. Standard VoI techniques will include the uncertainty inherent in early field development. Follow-on decisions for optimal facility design and timing should be evaluated on a fully stochastic basis that allows for the identification and mitigation of downside risk.

Given continuing economic viability, appraisal should continue until no significant decision will be affected by reduction of uncertainty. This is the ideal, but in a practical sense companies will have risk tolerance. Their portfolio may be able to trade-off reduction of uncertainty, and therefore security of return for earlier revenue potential. This risk allocation will not and should not be seen at the prospect level. It is important that evaluations be done in a risk neutral manner.

Multiple Prospect Comparison

Comparisons of individual prospects may be carried out similarly to the single prospect method. The major difference is found in volatility.

In the situation where a number of prospects are needed to obtain a certain threshold of reserves or production rate, the starting point will be the assessment of the variance for each prospect. Prospects may not be consistent in either variance or magnitude of the mean. Prioritization of different prospects, which contribute to an overall goal, must be evaluated not only on the basis of the variance, but the extent of variance reduction possible by prospect. Ranking of prospects by reducible uncertainty allows the allocation of funds to appraise based on a project's contribution to the cumulative uncertainty. Some projects have large but irreducible uncertainty. Additionally, attention must be paid to volatility.

Volatility is reflected in the relationship of the P10-P90 range with the mean of the distribution. This is important as the decision stability of a prospect with a mean of 300 MMBO and a P10-P90 range of 350 to 280 is quite different from a 60 MMBO prospect with a P10-P90 range of 30 to 100. It appears as though a factor needs to be applied that takes into account the volatility aspect as well as variance reduction. There have been several attempts at this, but none have been fully satisfactory to date from both a validity and practical application standpoint. Notwithstanding the presence of a volatility factor, the major impact will be variance reduction in the context of economics and decision materiality.

Different prospects typically require different levels of funding for appraisal drilling. The cost per unit of uncertainty reduction is a metric that may assist in the prioritization of prospects within a capital constrained environment.

Conclusion

Appraisal wells assess materiality.

Appraisal activities contribute to the reduction of uncertainty seen by the project. Specific learning objectives are at the core of the justification and a primary requirement of appraisal locations. Uncertainty reduction comes from two sources of learning: discrete learning events and population sampling, though population sampling in and of itself is insufficient to justify appraisal. Efficient appraisal programs provide the fastest, most cost effective path to establishment of reserves. Individual well locations are to be compared based on their ability to reduce overall uncertainty. Potential appraisal locations are compared on the basis of their outcome distributions and should be prioritized by expected uncertainty reduction potential. Initial distributions are the sum of their outcome distributions. Appraisal teams should assess outcome distributions and perform roll-ups to produce the initial distribution. Appraisal ends when sufficient certainty has been achieved to render futher appraisal learning as insufficient to cause significant change in decision path, acceptable decision risk remains, by virtue of the company's risk tolerance, or the field is seen to be sub-economic given the current uncertainty profile. Using these principles will provide an objective path forward for the planning and justification of appraisal well locations while preserving or delivering maximum value to the organization.

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References

Coopersmith, E.M., Cunningham, P.C.: "A Practical Approach to Evaluating Value of Information and Real Option Decisions in the Upstream Petroleum Industry" paper SPE 77582, presented at the SPE Annual Technical Conference & Exhibition held in San Antonio, Texas, USA, 29 September – 2 October, 2002.

Demirmen, F.: "Use of "Value of Information" Concept in justification and ranking of subsurface appraisal." paper SPE 36631, presented at the SPE Annual Technical Conference & Exhibition held in Denver, U.S.A., 6-9 October 1996.

________: "Impact of Seismic and Appraisal on Reserves Uncertainty – Expectation Versus Realism", Proceedings of the 59th EAGE Conference and Technical Exhibition, Geneva Switzerland, 26-30 May, 1997

________: "Subsurface Appraisal: The Road From Uncertainty to Better Economics", paper SPE 68603, presented at the SPE Hydrocarbon Economics and Evaluation Symposium held in Dallas, Texas, 2-3 April 2001.

Head, K.J.: "How Could You Possibly Predict the Value of 3-D Seismic before You Shoot it?" paper SPE 56446, presented at the 1998 Geo-Triad Convention in Calgary, Canada. 97-100.

Konix, I-P.M.: "Value of Information - from Cost~ Cutting to Value Creation," paper SPE 64390, presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition held in Brisbane, Australia, 16-18 October 2000.

Nutt, P.C., *Why decisions fail*, publish. Barret Koehler, 2002, ISBN1-57675-150-3

Whiteside, W., Drown, C., "General Solution for Option Analysis and Valuation Using a Branching Monte Carlo Method", paper SPE 71412, the 2001 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, 30 September–3 October 2001.

Winkler, R.L., *An Introduction to Bayesian Inference and Decision, 2nd ed.*, publish. Probabilistic Publishing, 2003, ISBN 0-9647938-4-9