STOCHASTIC MODELLING FOR REDUCING RISK IN PROSPECT EVALUATION

Paper presented at the AAPG Annual Convention, Houston, TX., March 1995
Session 007 DPA: Reducing Dry-Hole Risk (Maximising Investments in Oil and Gas).

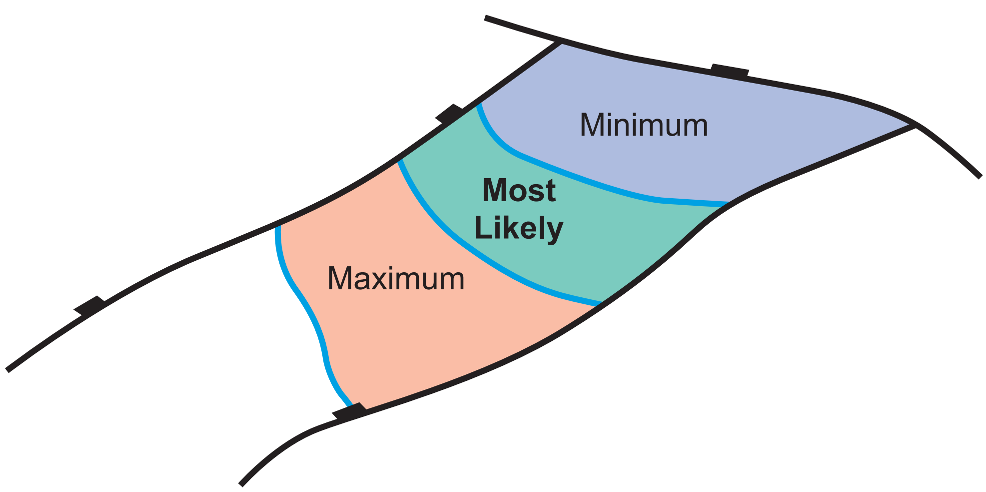
Richard Benmore Oryx UK Energy Company, Charter Place, Uxbridge, UB8 1EZ, UK
Michael Cooper Oryx UK Energy Company, Charter Place, Uxbridge, UB8 1 EZ, UK
Barrie Wells Conwy Valley Consultants Ltd, Premier House, Llandudno, LL302YA, UK

The practical definition of a dry hole is one that fails to prove an economic volume of producible hydrocarbons. This paper examines ways of reducing dry hole risk through better prediction of hydrocarbon volumes. This is particularly desirable in the exploration and appraisal of satellite structures where the classic geological risks of trap, source rock, reservoir, seal, and migration pathways are often negligible with proven analogue's all around. The major uncertainty is generally whether the volume present is economic, and therefore the volumetric assessment is critical.

Risk reduction is realised by either decreasing the number of dry holes drilled or by increasing the number of successful wells drilled. Eliminating over-optimistic evaluations also achieves this reduction. The exploration drilling history within any basin, however, shows us many examples of successful prospects that have been overlooked on first examination. The success ratio can also be improved by drilling more of these prospects. The example prospect was drilled and is a success but it was previously overlooked, partly due to a pessimistic risk assessment of the prospectivity.

The example is a North Sea satellite prospect. Satellite fields, made economic by the existence of nearby infrastructure, are increasingly important in the North Sea. They maximise return on invest-ment by reusing existing facilities. Concurrently, they also place greater demands on the geoscien-tist's ability to assess the risk of success. By it's very nature, a satellite is bound to be a close eco-nomic decision based on the volumetric assessment and the estimated risk.

The example prospect is a simple down-thrown fault block, as shown below:



The prospect was assigned the following 'Most Likely' volumetric parameter values, derived from a knowledge of many wells in surrounding fields within a similar geological setting.

Input Parameter	Value
Gross Rock Volume	70150 acre-ft
Porosity	18%
Net-to-Gross	40%
Hydrocarbon Saturation	48%
Formation Volume Factor	1.25 rb/stb
Recovery Factor	15%

The minimum economic volume of recoverable hydrocarbons for this prospect was calculated to be in the order of 3MMBO. Unfortunately, even this relatively modest recoverable reserves figure cannot be achieved from the 'Most Likely' deterministic assessment.

GRV x Ø x N/G x Sh / FVF x RF x [unit conversion factors] = 2.3 MMBO

However, with satellite prospects the geologists knowledge is rarely limited to six simplistic summary values. In this instance, the prospect was within a mature province (by North Sea standards) with a well density approaching one well per 1000 acres. The available database allowed confident evaluation of ranges for each physical parameter.

Input Parameter	Downside	Upside
Gross Rock Volume	7600 acre-ft	246 400 acre-ft
Porosity	14%	24%
Net-to-Gross	26%	58%
Hydrocarbon Saturation	15%	78%
Formation Volume Factor	1.38 rb/stb	1.12 rb/stb
Recovery Factor	10%	30%

This results in a corresponding deterministic range of reserves:

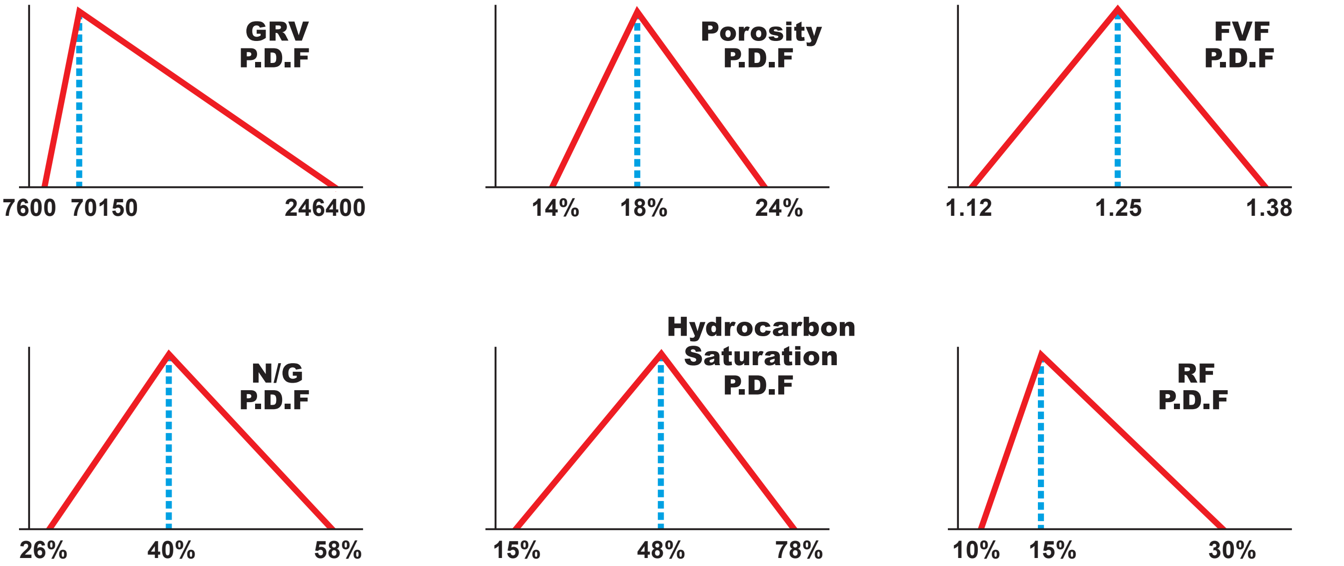
Downside
0.03 MMBO

Upside
57 MMBO

The results using the extremes, yield a minute downside case and a huge upside case that are little practical use to decision-makers. A reliable method to factor this high risk/high reward scenario into the evaluation is required.

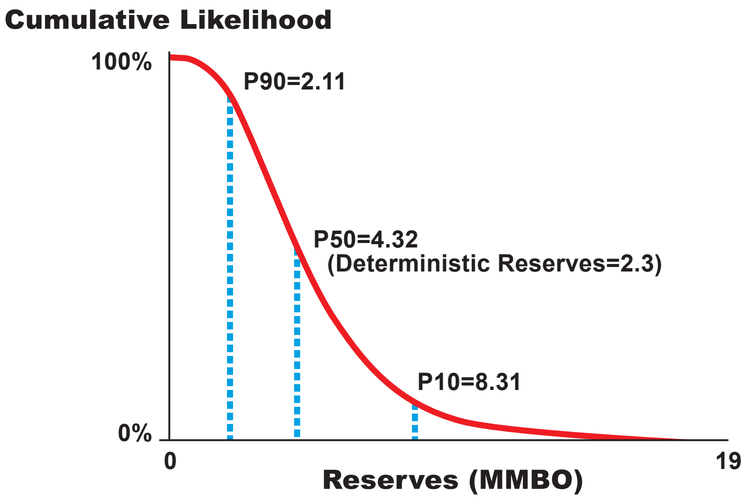
Stochastic Modelling

Stochastic modelling allows more geological knowledge of the prospect to be included in a reserves assessment. An estimate of the probability for every possible value, for each parameter, is required. This is the Probability Density Function (PDF). Simplistically, the downside and upside values may be considered extreme values, beyond which there is zero chance and between which the probability increases to reach its highest level at the "Most Likely" value. The triangular PDF’s for the example prospect are shown below:



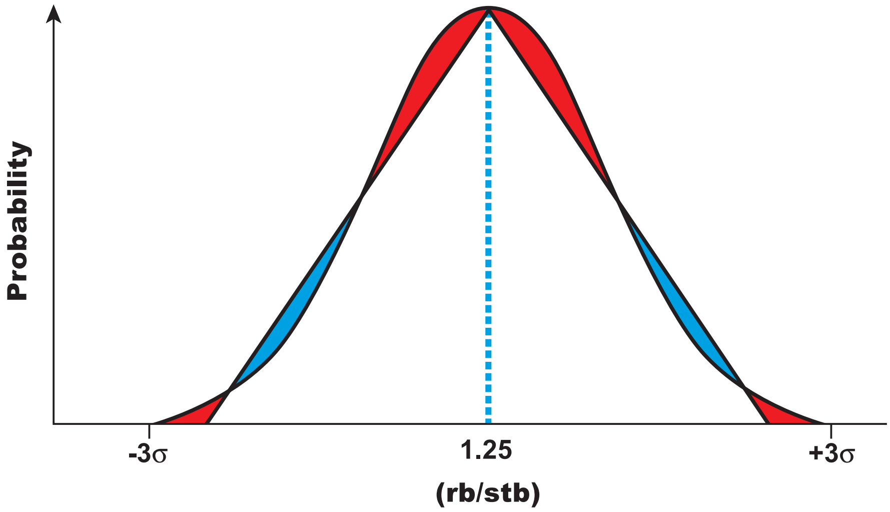
Many oil & gas companies use triangular distributions, and papers by Smith (1970), Smith & Buckee (1985) and Øvreberg *et al* (1992) illustrate their use.

Using a Monte Carlo technique to generate the probability of all possible outcomes we obtain a probability for each possible reserves figure. A graph of the cumulative probability of the outcomes is shown below:



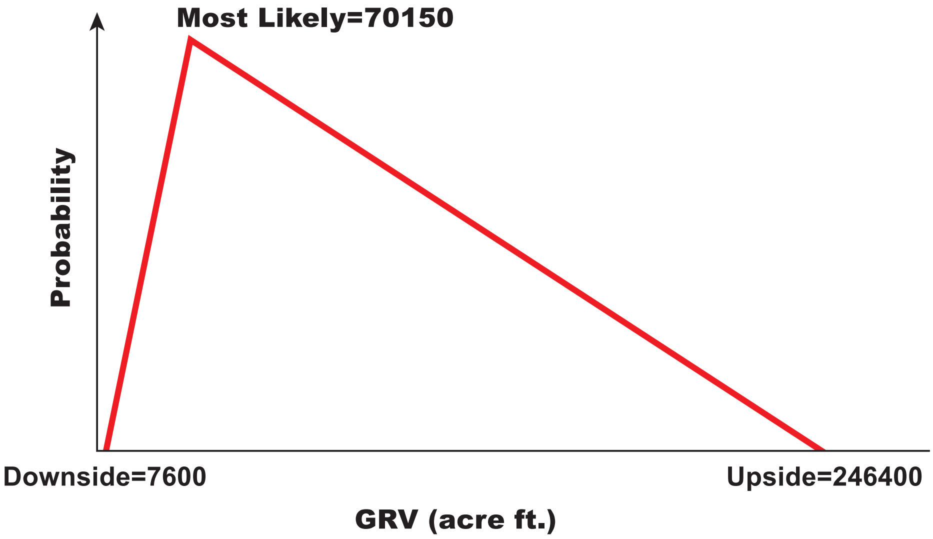
The expected value of recoverable reserves (taken as the P_{50} value on the cumulative probability curve) is now 4.3 MMBO. The upside potential has increased the estimate of the expected reserves above the 3 MMBO economic hurdle, which adds credence to the recommendation to drill the prospect. However, before taking this decision, the validity of the assumptions should be checked.

The main assumption was to simply join the three points given as downside, “Most Likely" and upside, to produce a triangular PDF. The triangular distribution is, at best, a first approximation. For example, the Formation Volume Factor (FVF), includes the unnatural condition that FVF can never be less than 1.12 nor greater than 1.38. The geologist is fairly confident from nearby analogues that the range 1.12 - 1.38 is reasonable. However, this does not necessarily mean that there is a zero chance of the FVF being, for example, 1.10.



Real physical phenomena are more likely to follow a normal distribution. Furthermore, the bell curve allows very small, but not zero probabilities to be allocated to extreme (very unlikely) events: Although satisfied the model is more realistic, the resultant difference in calculated reserves is small. Both the triangular and normal distributions must have the same area under the curve, since the sum of all probabilities of all possible events must be unity. Therefore, the positive and negative areas, where the triangular distribution over- or underestimates relative to the normal distribution, tend to cancel each other out. The normal distribution is theoretically more rigorous, but makes little difference to the outcome.

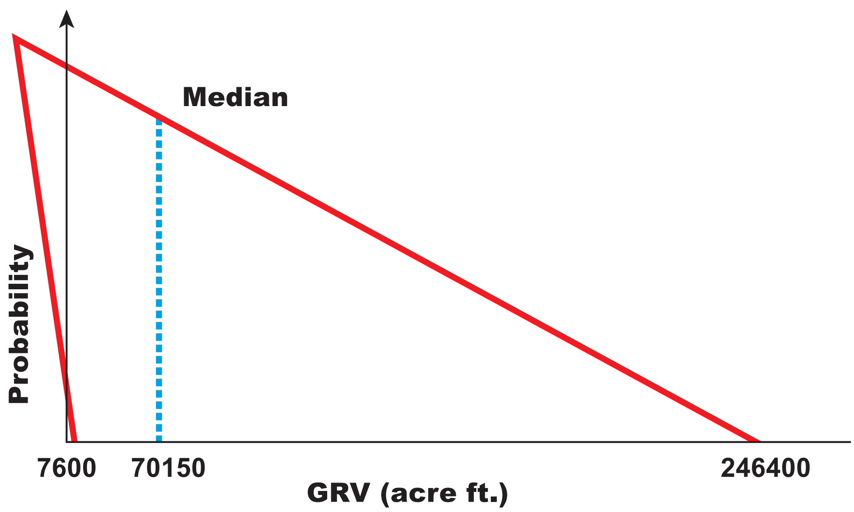
However, asymmetric distributions definitely require more appropriate modelling as they greatly affect the model. For example, in the Gross Rock Volume PDF, the "Most Likely" point is assumed to be the apex of the triangle as shown below:



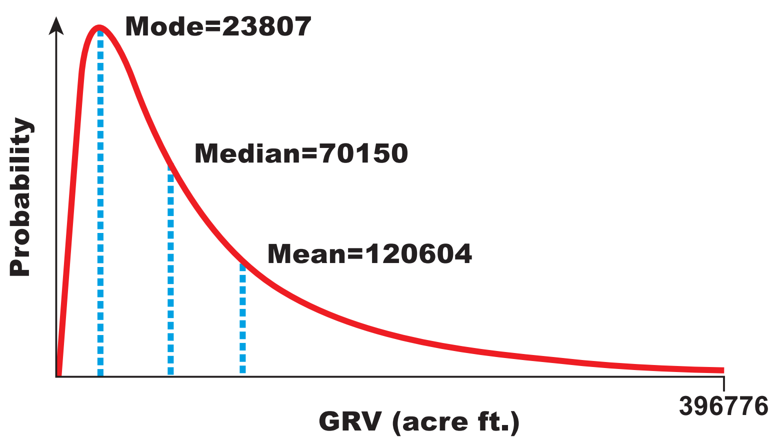
This may not be the geologists intention. "Most Likely" should imply a value for which there is as much likelihood of it being too small as there is of it being too large. An alternative notation is P_{50}. This definition most closely describes the median - the midpoint value, when lining up all the possibilities in order.

Mode, median and mean all coincide for well behaved, uni-modal, symmetric distributions, but for asymmetric distributions they do not. Hence, for the symmetrical FVF example it does not matter how "Most Likely" is interpreted. For asymmetric parameters, however, it is critically important to understand the intention behind the assessment of the "Most Likely".

If the apex of the triangular distribution is correctly identified so that the "Most Likely" GRV of 70,150 acre-ft represents the median, an impossible distribution results:



In the same manner the triangular distribution of the symmetrical FVF was replaced by a normal distribution, the problem of asymmetric distributions can be solved by adopting lognormal distributions. This is both theoretically correct [Krige (1960), Krumbein (1936)] and a better model for the mean/median/mode distinction.

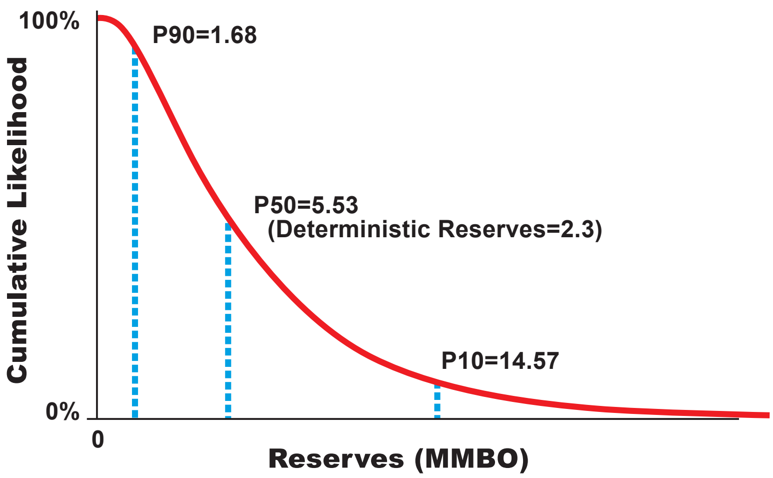


The identification of the geologists "Most Likely" with the modal value is clearly wrong, both heuristically and theoretically. Indeed, there is arguably little practical meaning to the mode for a continuous distribution, since, by definition, the probability of any individual value is zero. The choice between mean and median is, however, less clear.

The distinction is more philosophical than technical. Both measures attempt to capture the essence of "middle value". Median has no regard to the value of the variable whereas mean places more weight on large extreme values. Fortunately, statistical theory does provide some guidance. For any positively skewed asymmetric distribution, the relationship [mode < median < mean] holds. For log-normal distributions, the median is about twice as close to the mean as it is to the modal value. Median and mean are quite similar, at least compared with the mode. There is little difference in assigning the "Most likely" value to either median or mean, provided there is consistency.

It is therefore a question of corporate philosophy, which is adopted in the model. Some companies may prefer to choose the mean to place more emphasis on high risk, high reward prospects. Others may favour lower risk and lower reward ventures, preferring the median. For the purposes of this paper, "Most Likely" is identified with the median.

Now, fitting lognormal distributions to all the prospect parameters, an economically viable prospect with expected recoverable reserves of 5.5 MMBO is predicted:



The result is greater confidence in the viability of the prospect, having increased the probability of finding economic reserves. The increase in expected reserves, from 4.3 MMBO to 5.5MMBO, resulting from use of the (more justifiable) lognormal distributions, illustrates the importance of choosing the correct inputs to the stochastic model. However, few geologists are also statisticians. Therefore in practice, large differences can occur in setting up a model, and this typically leads to large discrepancies between results.

Consistency

It is essential to introduce consistency in setting up a stochastic model to compare and rank competing prospects. Maximising the comparability, repeatability and consistency between prospect evaluations increases the chances of the best prospects being drilled and therefore reduces dry hole risk.

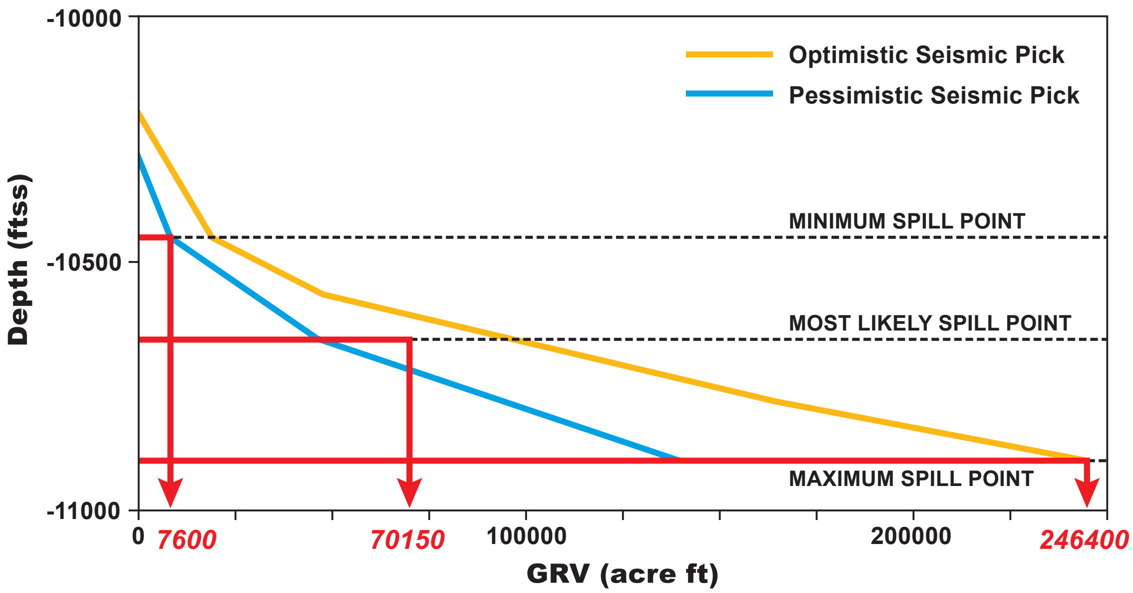
There are three main areas where consistency can be increased:
i. Appropriate level of granularity in the parameters.
ii. Consistent application by individual geologists.
iii. Systematic interrelationships between pairs of variables.

i. Appropriate level of granularity in the parameters

Granularity refers to the component parts, which determine the value of a product. For example, uncertainty in the estimate of STOOIP is derived from uncertainty in each of the parameters that characterise STOOIP (e.g. gross rock volume, porosity, etc). However, these "obvious" parameters are not necessarily at their lowest level (most granular) to estimate uncertainty. Uncertainty in gross rock volume stems from not just one, but many, factors, such as the geological model (trap), depth conversion, seismic interpretation, and spill-point.

In the example the trap is a simple, well defined, down thrown fault block that does not require multiple modelling. The depth-conversion is also straightforward because there is no significant spatial velocity gradient. This means that any error in the depth-conversion will elevate or depress the whole structure, but not significantly influence the volume of the trap.

The two remaining factors, seismic interpretation and spill point, both exert important controls on the uncertainty in gross rock volume:



The two different seismic interpretations reflect differences in the base reservoir seismic pick, and the three spill points reflect the likely range of columns that could be expected from this type of trap in this area. The minimum GRV is therefore obtained as the minimum spill point taken with the pessimistic seismic pick, the "Most Likely" is obtained from the averages and the maximum GRV from optimistic seismic pick and maximum spill point.

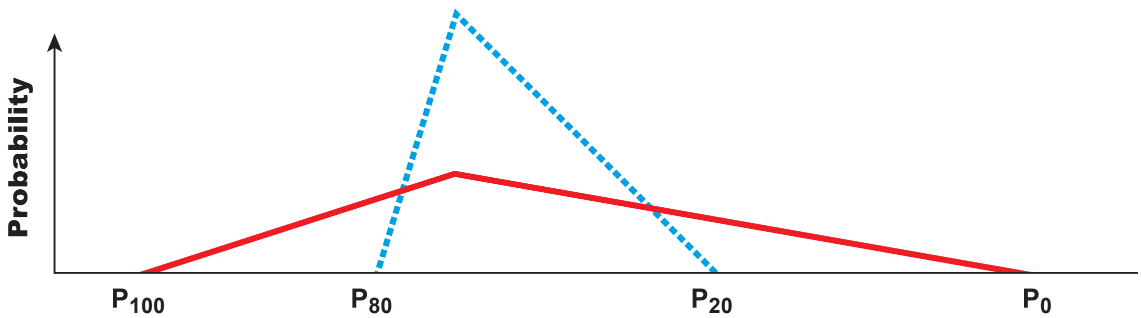
Unless there is a causal or observational relationship between any input parameters, they must be entered into the Monte Carlo model separately.
The correct choice of parameters (i.e. the right level of granularity) is crucial.

ii. Consistent application by individual geologists

The principle difference between two geologists, or even occasionally for a single geologist, is the way in which the PDF is constructed from available data. There are two components to this; choice of distribution type and characterisation of the chosen type. We believe there is a strong case for using normal and lognormal distributions. Adoption of this throughout a company, if not throughout the industry, immediately removes one cause of inconsistency.

The second problem, characterising the distribution curve, arises partly because few geologists are statisticians, and partly because people are inherently poor at assigning probabilities to unlikely events, whether or not they have training in statistics. Describing a distribution largely by reference to extreme values is inherently inaccurate, because by their very nature these are the rare examples whereby just one extra or one less rare occurrence makes a huge difference. In the North Sea, for example, the height of the "hundred year wave" (used in the design of rigs and platforms) has been raised by 5 meters in the last four years. Previously, oceanographers had incorrectly assigned the probability of this event.

In addition, the definitions ascribed to extrema are themselves poorly defined. For example, "minimum" may mean an attainable value to one geologist and an unattainable value to another. Frequently, as in the first attempt above, extrema are interpreted literally, giving a 100% confidence on the limits (Smith, 1970). Smith and Buckee (1985) however, propose limits of either P_{95} and P_5 or P_{90} and P_{10}. In contrast, Øvreberg *et al*, (1992) suggest the downside has an 80% chance and the upside a 20% probability point. The difference between identifying (downside,upside) with (100%, 0%) and (80%, 20%) is dramatic:

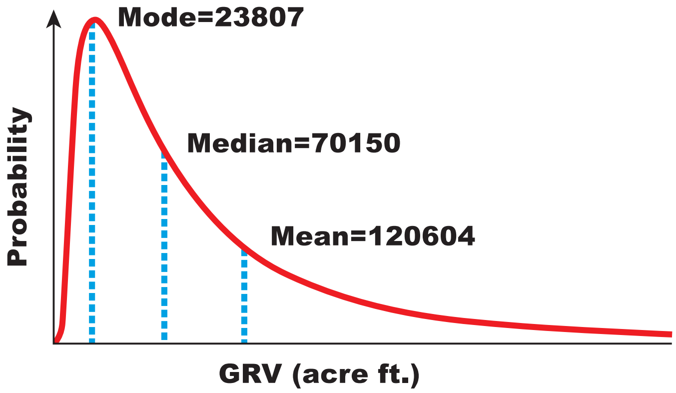


Unfortunately, there is no correct answer to the question of endpoints, and even if there were, it would be an unsatisfactory and error-prone method of characterising distributions.

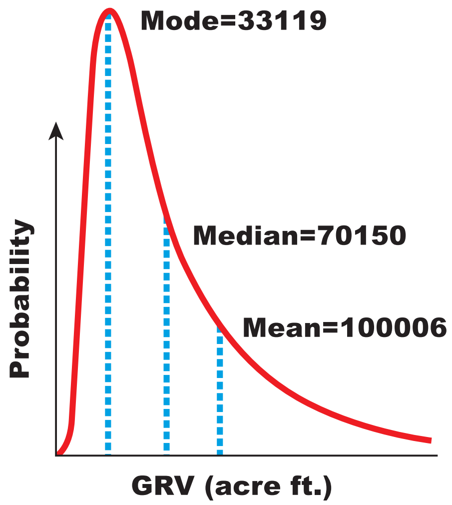
Perhaps the most effective way of removing this cause of inconsistency, would be for geologists to construct the distributions from terms of more familiar and repeatable characteristics. However, the geologist's expertise in the assessment of each "Most Likely" value is crucial.

We have tried to capture the user's expectations of variability from a natural language description and compute a distribution from this description. Distributions are characterised for each parameter by the amount of skewness and the degree of asymmetry. The geologist's assessment of the "Most Likely" is considered inviolate and the remainder of the information is modelled by deviations from the norm, rather than unreliable predictions of the extremes. This is all achieved through software which hides the complexity and performs all necessary statistical calculations, allowing geologists to express themselves in geological terms, without risk of misinterpretation.

1. P_5, P_{95}



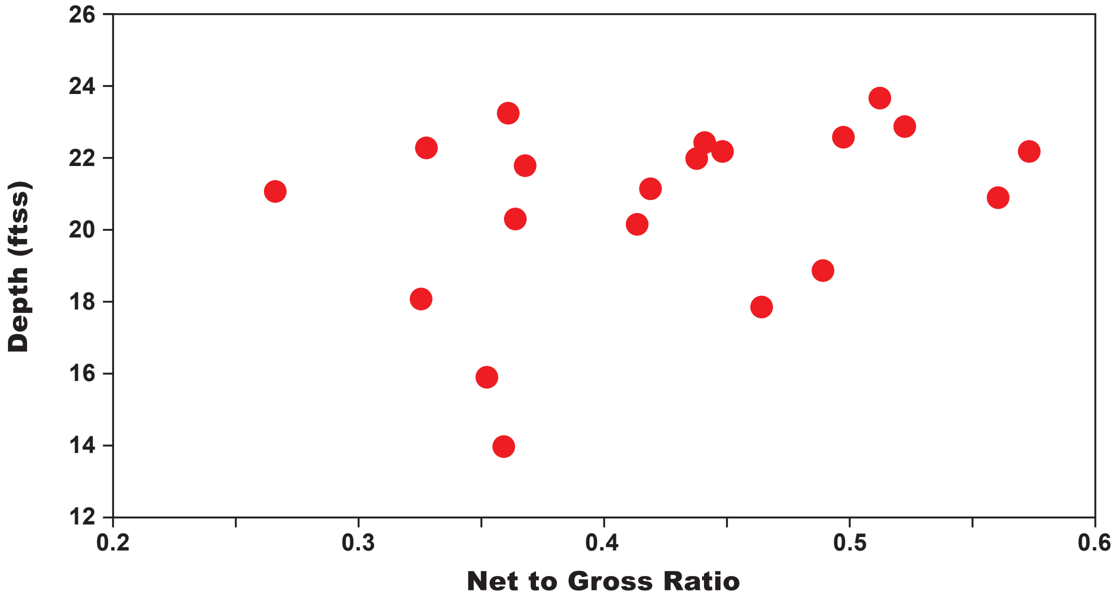
2. P_1, P_{99}



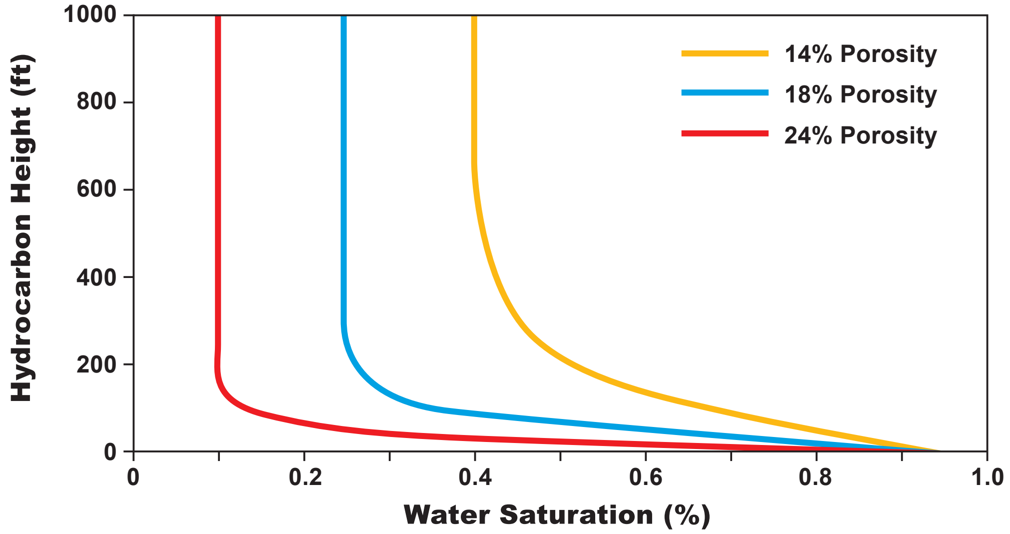
iii. Systematic interrelationships between pairs of variables

There are inevitably relationships between the parameters, and these will affect the spread and central tendency of the calculated reserves distribution. The basic premise of the Monte Carlo technique is that it is unlikely that everything will go wrong simultaneously. The technique was pioneered by the Manhattan project workers for modelling molecular-scale phenomena. Atomic particles appear to move randomly. It is possible that all the particles in an object could decide to move in the same direction for a short while, so causing it to jump across the room. Though possible, it is extremely unlikely. The motions of all particles are independent, and cancel each other out, so objects stay in the same place.

The parameters that decide a prospects economic viability are generally independent. In the satellite example, the available data suggests there is no obvious relationship between porosity and net-to-gross values:



However, some parameters do exhibit dependency. The 'J' curves for nearby fields show that porosity has a clear control on water saturation (SW) and therefore hydrocarbon saturation (Sh):



The Monte Carlo method may be modified to account for such systematic interrelationships between pairs of variables, provided the relationships are characterised. Additionally, capturing the correct level of granularity for each parameter reduces the effect. The authors are continuing to examine different ways of modelling granularity and characterising systematic interrelationships.

Conclusions

Dry hole risk can be decreased by either drilling fewer dry holes or drilling more successful wells. Some prospects are sufficiently large to be drilled despite the volumetric evaluation procedure used. Of these, some will inevitably be dry. Consistent and theoretically correct stochastic modelling is unlikely to influence decisions on whether to drill such large, standalone prospects.

This paper illustrates how critical it is to undertake theoretically correct risk analysis when evaluating smaller satellite prospects. In the example, the deterministic "Most Likely" reserves figure of 2.3MMBO was below the economic threshold, but with further consideration of the data and stochastic modelling, the P_{50} value of 5.5MMBO exceeded the threshold.

Satellite prospects in mature provinces are particularly suited to stochastic modelling of volume assessments because there is a wealth of geological data available. It is essential the analysis is undertaken consistently to allow a fair comparison of competing prospects, so the drilling budget is allocated efficiently and the risk of drilling uneconomic wells is reduced.

The best geological assessment is wasted if it is not supported by the best statistical analysis of volumetric evaluation.

Acknowledgements

The authors would like to thank John Kipps for creating the slides for the talk and the figures for this paper and many colleagues within Oryx UK Energy Company for valuable discussions.

References

Behrenbruch, P., Turner, G.J. and Backhouse, A.R. (1985) " Probabilistic Hydrocarbon Reserves Estimation: a Novel Monte Carlo Approach", Offshore Europe 85, Aberdeen (SPE 13982/16)

Krige, D. G. (1960) "On the departure of one value Distributions from the Lognormal Model in South African Gold Mines", Journal of the South African Institute for Mining and Metallurgy, 61, 231-244

Krumbein, W. C. (1936) "Application of Logarithmic Moments to Size Frequency Distributions of Sediments", Journal of Sedimentary Petrology, 14, 547-555

Øvreberg, O., Damsleth, E., and Haldorsen, H. H. (1992) "Putting Error Bars on Reservoir Engineering Forecasts"; SPE.

Smith,.M. B. (1970) "Probability Models for Petroleum Investment Decisions", Journal of Petroleum Technology.

Smith, P. J. and Buckee, J. W. (1985) "Calculating In-Place and Recoverable Hydrocarbons: A Comparison of Alternative Methods"; SPE 13776.