Taking a Calculated Risk

Engineers, mathematicians and other experts have devised many tools to help us understand uncertainty and to evaluate and mitigate risk. The oil industry is permeated by uncertainty and encounters risk at every turn, yet many oilfield decision-makers, perhaps most, give the new techniques a wide berth.

William Bailey
Aberdeen, Scotland

Benoît Couët
Ridgefield, Connecticut, USA

Fiona Lamb
Graeme Simpson
University of Aberdeen
Aberdeen, Scotland

Peter Rose
Rose & Associates
Austin, Texas, USA

For help in preparation of this article, thanks to Ben Ball, Massachusetts Institute of Technology, Cambridge, USA; Kent Burkholder, Merak, London, England; Keith Leslie, McKinsey & Co., London, England; Steve McColl, Conoco, Aberdeen, Scotland; Patrick McIntosh, Det Norske Veritas, Aberdeen, Scotland; David Morgan, Uncertainty Management, Hertford Heath, Hertfordshire, England; Bill Pace, Imperial College of Science, Technology and Medicine, London, England; Sam Savage, Stanford University, California, USA; Michael Walls, Colorado School of Mines, Golden, Colorado, USA; and M.W. Whiteside, Indeva Energy Consultants, Henley-on-Thames, England.

The oil industry is riddled with risk and uncertainty. Both loom so large at almost every stage of the business—exploration, production and downstream marketing—that the industry is regarded as a classic illustration of the need for sophisticated approaches to risk assessment. Yet the evidence suggests that although many rigorous assessment tools are available, they are underutilized. Even the largest companies often use intuition and experience rather than science when asked to appraise investment opportunities and decide whether to commit funds to particular projects.

Properly assessing risk and uncertainty confers a competitive advantage. Research done at the University of Aberdeen, Scotland, into the decision-making practices of 20 companies active in the North Sea has established a strong positive correlation between the degree of sophistication in companies' decision analysis and the success of their investment decisions. The research also shows that there are glaring gaps in the use of available tools. Tools that can be, and are, used to cope with physical risk and uncertainty are practically ignored when economic risks and uncertainties are in question.[1] Tools involving probabilistic analysis are used to capture the uncertainty involved in, say, determining the recoverable reserves in a field, but not to assess the economics of developing a field under conditions in which costs and oil prices vary.[2]

Many tools are available to help companies maintain a competitive advantage through properly assessing risk and taking the appropriate amount of risk (see "Risk, or Chance of Success, Estimation," *page 22*). These include, in roughly ascending order of sophistication: discounted cash flow, Monte Carlo analysis, and portfolio, options and preference theory. This article discusses each technique in detail and presents case studies to demonstrate their use in assessing risk in the oil and gas industry.

1. In this article, the terms risk and uncertainty are used in the same way as most of those in the oil and gas industry use them, according to the Aberdeen study discussed later in this article. "Risk" means the chance, likelihood or probability of something happening, and "uncertainty" refers to the range of possible values or sizes of that something, if it happens. An alternative set of definitions, which is perhaps better and more rigorous, but not yet in common use in the industry, would include three terms: chance, uncertainty and risk. "Chance" refers to the likelihood or probability of something occurring, "uncertainty" refers to the range of possible outcomes (given that something occurs at all), and "risk" refers to the threat of loss contained in a chancy business venture with considerable uncertainty as to range of possible outcomes.
2. Simpson GS, Lamb FE, Finch JH and Dinnie NC: "The Application of Probabilistic and Qualitative Methods to Asset Management Decision Making," paper SPE 59455, presented at the SPE Asia Pacific Conference on Integrated Modeling for Asset Management, Yokohama, Japan, April 25–26, 2000.

Discounted Cash Flow

Discounted cash flow (DCF) analysis, the most widely used investment-appraisal tool in the oil industry, embodies a concept that is crucial to an industry whose investment time scales are often measured in decades rather than years—namely the time value of money. The time value of money is based on the idea that an amount of money received at some point in the future is worth less than the same amount received today. In the North Sea, there is an average gap of seven years between initial exploration expenditure and the commitment to develop a discovery. It takes another three or four years to begin production, and then fields normally produce for around 20 years before they are abandoned. Most of the main costs, or cash outflows, are incurred in the earlier exploration and development years, while the cash inflows, or revenues, are spread over the active productive lifetime of the field.

Cash received later—in this case, the revenues received from the produced oil—is worth less than the same sum paid at an earlier date because it has not been available to earn interest in the intervening years.

DCF analysis is a way of determining the value today of money spent and—assuming success—received in future years. The associated concept of net present value (NPV) enables those who are evaluating potential investments to determine whether an investment should proceed or not. The net present value is the sum of the discounted cash flows and represents the difference between the present (discounted) values of the cash outflows over the projected life of the project and the present values of the cash inflows.

If the NPV is positive, the required rate of return is likely to be earned, and the project should be considered. If it is negative, the project should be rejected. A key element in the calculation of NPV is the discount rate applied. This can be considered in several ways. For example, there is the risk-free rate of return that a bank would offer for depositing money. If using that rate in the calculation yields a negative NPV, then it would be better to put the money in the bank. A positive NPV means investing the money in the project is better than putting it in the bank. An alternative is to ask what it costs to borrow the money, either from shareholders or the bank, then discount at that rate.

An example of discounted cash flow analysis can be shown in tabular form (left). Using a 10% discount rate, the value of a $2,000 net cash flow ($2,500 of revenues less $500 of operating expenses) that is received in year 5, as a result of investing $5,000 today, is worth $1,242. The total NPV in this example (the sum of all the discounted

Year	Investment	Revenue	Operating expense	Net cash flow	10% discounted net cash flow	20% discounted net cash flow
0	$5,000			–$5,000	–$5,000	–$5,000
1		$2,500	$500	$2,000	$1,818	$1,667
2		$2,500	$500	$2,000	$1,653	$1,389
3		$2,500	$500	$2,000	$1,503	$1,157
4		$2,500	$500	$2,000	$1,366	$965
5		$2,500	$500	$2,000	$1,242	$804
Total	$5,000	$12,500	$2,500	$5,000	$2,582	$982

^ Discounted cash flow. This example shows the net present value (NPV) growth of $5,000 invested using a 10% discount rate. [Adapted from Jones DR: "Some Basic Concepts," in Steinmetz R (ed): *The Business of Petroleum Exploration*. Tulsa, Oklahoma, USA: American Association of Petroleum Geologists (1992): 9.]

Risk, or Chance of Success, Estimation

The first step in any rational analysis of an opportunity is a subjective estimation of the chance of a least some minimal measure of success—for example, the chance of finding oil and gas, as opposed to drilling a dry hole. Chance of success is binary, and may be likened to an on-off switch. If the chance of something happening is estimated to be X%, then the chance of that thing not happening is 100% minus X%. Generally, chances of success estimates are broken into two categories: below-ground and above-ground estimates. "Below-ground" chance estimates in exploration and production (E&P) tend to be the concern of geoscientists and engineers considering geological evidence bearing on the likelihood of hydrocarbon presence, reservoir and trap presence and other technical input. "Above-ground" chance estimates may focus on elements of politics, world economics and technological developments, which are the natural purview of experts in governmental affairs, finance and technology.

Characteristically, experts make all estimates of chance, often working collectively, and considering known facts, past experience and all possible scenarios. Surprisingly, explorationists tend to be conservative when estimating chance of success for "midrange" projects—those thought to have a moderate 25% to 60% chance of success. Such projects are often successful about 35% to 75% of the time.[1] However, for "high-risk" projects—those thought to have less than 20% chance of success—explorationists have historically proven overly optimistic. Taken as whole, such ventures have found oil less than 5% of the time.

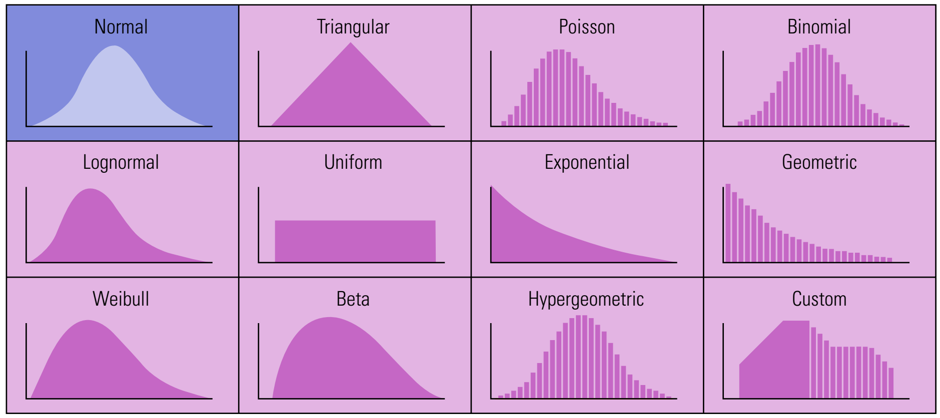
1. Alexander JA and Lohr JR: "Risk Analysis: Lessons Learned," paper SPE 49039, presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, September 27-30, 1998.
   Otis RM and Schneidermann N: "A Process for Evaluating Exploration Prospects," *AAPG Bulletin* 81, no. 6 (July 1997): 1087-1109.
   McMaster GE and Carragher PD: "Risk Analysis and Portfolio Analysis: The Key to Exploration Success," *Proceedings of the 13th Petroleum Conference—Exploration*, vol 2. Cairo, Egypt: The Egyptian General Petroleum Corporation (1996): 415-423.

Recoverable reserves

$$N_r = (GRV) f \phi S_h \varepsilon_r B$$

N_r	=	recoverable reserves
GRV	=	gross rock volume
f	=	net pay/gross pay ratio
ϕ	=	porosity
S_h	=	hydrocarbon saturation
ε_r	=	recovery efficiency
B	=	shrinkage or expansion factor

^ Formula for estimating recoverable hydrocarbons. Gross rock volume is the total volume of the "container" mapped out by the geoscientists. Net pay/gross pay is the proportion of the container that is reservoir rock (for example, sand) as opposed to nonreservoir rock (shale). Porosity is a measure of the fluid storage space, or pores, in the reservoir rock, as opposed to sand grains. Hydrocarbon saturation is the proportion of fluid in the pore spaces that is hydrocarbon as opposed to water. Recovery efficiency is the proportion of producible hydrocarbons in the reservoir. The shrinkage or expansion factor accounts for the volume shrinkage or expansion of hydrocarbons as they travel to the surface. For hydrocarbons that are liquid in the reservoir, the release of pressure resulting from transport to the surface allows gases to come out of solution, and the volume of liquid shrinks. For gas, the situation is reversed; a reduction in pressure causes gas expansion, so the volumes of gas at the surface exceed the reservoir volume.



^ The various shapes of distributions. The best known is the 'normal' curve, whose shape was first recognized, in the 17th Century, by the English mathematician de Moivre. The curve is bell-shaped and symmetrical. Its mean, mode and median are all in the center. The normal distribution describes many natural phenomena, such as people's IQs or heights. A triangular distribution describes a situation in which the minimum, maximum and most likely values to occur are all known. In a uniform distribution, the rectangular shape indicates that all values between the minimum and maximum are equally likely to occur. The skill of the geologist or engineer lies in deciding which curve best describes the situation being examined, like the spread of possible porosities of a reservoir rock.

net cash flows) is $2,582. In other words, the $5,000 is recovered, plus a 10% return, plus $2,582. If the $5,000 had been invested in a bank at 10% interest, the return would be $2,582 less than an investment in this project.

The usefulness of DCF is limited by its insensitivity to the changing circumstances and long time scales in the oil industry. To surmount this shortcoming, DCF is often used in conjunction with a technique known as sensitivity analysis, in which the consequences of possible changes to the variables are examined. Changes to interest rates, cash flows and timing are fed into the calculation to determine the value of the project if such changes actually occur. Used together with DCF, sensitivity analysis allows for a limited number of "what if" scenarios, but the choice of which variables to alter and how to alter them is highly subjective.

While DCF combined with sensitivity analysis may give decision-makers a better idea of the potential positive and negative outcomes of an investment, it makes no attempt to quantify the probability of any given outcome, information that would be extremely valuable to the decision-maker.

Monte Carlo Simulation

Monte Carlo simulation brings risk and uncertainty center stage as integral parts of the calculations rather than as afterthoughts. Most importantly, it brings probability into the picture. This statistical technique addresses the question, "If something happens, then what is the range of possible outcomes." It yields probability versus value relationships for key parameters. It can be used to answer technical questions—What is the range of recoverable reserves of hydrocarbons in this acreage?—and economic ones—What is the probability that the NPV of this prospect will exceed the target of $X million?

It is easiest to see how Monte Carlo simulation works by examining the comparatively straightforward task of determining recoverable reserves from an underground prospect (above left).

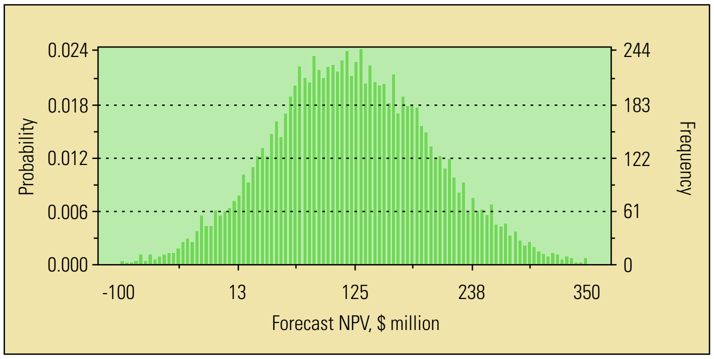
If reservoirs were homogeneous, it would be simple to work out the recoverable reserves in a prospect using a unique value for each parameter. But, in practice, it usually is not possible to assign such single values to each parameter. Geologists and engineers have to estimate fieldwide average values for properties like porosity and gross rock volume (GRV) on the basis of incomplete information.

What they can do with the limited data they have, however, is to draw a distribution—a curve that describes the probability of a particular value occurring—for each input variable. If, for example, the range of possible porosities for sandstone is typically between 10 and 35%, the distribution curve relating probability on the vertical axis to the porosity value on the horizontal one would describe the probability of each porosity value occurring.

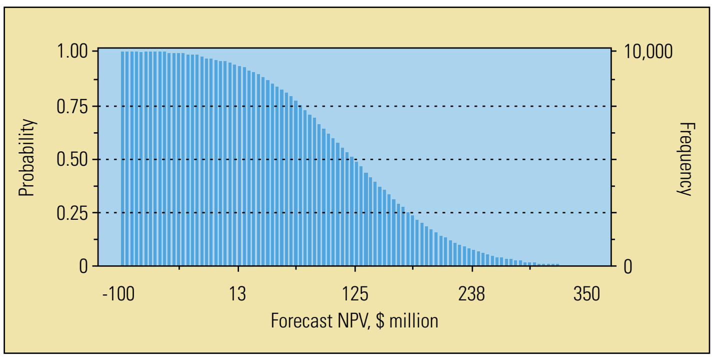
Similar distribution curves can be drawn for all the other inputs. In a Monte Carlo simulation, each of these inputs is then randomly sampled and the individual values multiplied together (a procedure known as a "trial"). The result of a single trial provides one possible answer for recoverable reserves. This random sampling of each of the input distributions is repeated many times—typically between 1000 and 100,000 depending on the type of calculation being performed. With so many trials, the simulation will sample the most likely outcomes of each distribution more than the extremes because there are more examples in that range. The end result is a new distribution curve—a range of possible recoverable reserve sizes and the probability of any particular value occurring.

In an ideal world, the individual distribution curves would be based on many measurements. But, in practice, the data available are often minimal. Discipline experts who bring their experience to bear will suggest the shape of the curve that is consistent with the small amount of data available. For instance, geologists often draw analogies between the porosity of the rocks being examined and the porosity of rocks from a similar previously exploited area.

The shape of distributions can vary enormously (above right). A triangular distribution, for instance, might be chosen for porosity if the experts were confident that they knew the minimum, most likely,



Percentile, %	Value, $ million
0	–112
10	27
25	71
50	122
75	176
90	223
100	422



^ Monte Carlo simulation results. A Monte Carlo simulation, named after the casino in Monte Carlo where systems for winning at various games of chance are often tried, shows the entire range of possible outcomes, such as net present values (NPV) of an asset shown on the X-axis and the likelihood, or probability, of achieving each of them *(top)* shown on the Y-axis. The frequency of each outcome for 10,000 trials is also shown on the Y-axis. The simulation does not give a single answer, but a range. It provides the decision-maker with the "big picture." Several examples taken from the forecast probability distribution and frequency plot are shown in the table *(middle)*. The reverse-cumulative probability distribution *(bottom)* shows the likelihood of obtaining an NPV greater than a value on the X-axis.

and maximum porosities. A lognormal distribution might seem most appropriate for GRV, indicating that the experts think that the range is greater on the high side than on the low side.

Monte Carlo simulation is widely used for estimating reserves, yet only a small number of companies use it as an aid to economic decision-making, or to assess political and safety risks, though the principles are the same (see "Unconventional Risks," *next page*). This suggests an unusual perception of risk—that it exists and is important in the physical world, but is somehow absent in the economic one. That clearly is not the case as the gyrations of oil price, costs, interest rates and many other financial factors have shown over the years.

The following example considers a hypothetical field with recoverable reserves of 150 million barrels [2.4 million m^3] of oil (MBO). Yearly production immediately reaches a plateau of 12% of total reserves, that is, 18 MBO/yr [2.8 million m^3/a] for 5 years, then declines at 20% per year thereafter, until all 150 MBO have been produced. Five production wells are needed, at a cost of $15 million per well over two years. Platform and pipeline costs are $765 million over three years. Operating costs are $75 million per year, and abandonment expenditure after last production is $375 million. Corporation tax is 30%, inflation is 3.5% throughout the period, and the discount rate is 10%. Oil price is assumed to be $18 per barrel, rising at the rate of inflation.

A simple deterministic net present value calculation gives a nominal net present value, discounting the cash flow at 10% per year (NPV_{10}) of $125 million. This is a positive number, so the decision to proceed with development should be straightforward.

But a probabilistic assessment of the same field gives the decision-maker a broader picture to consider. Assume the probabilistic assessment uses the above figures as the most likely inputs (those falling at the midpoint of the range) but also suggests the following ranges of possible values for inputs: drilling, capital and operating expenditures are assumed to be normally distributed with a standard deviation (SD) of 10% about the mean. Abandonment expenditure is normally distributed, with a SD of 20% of mean. Production volumes are also normally distributed, but with a positive correlation to operating expenditure.

Future oil price over the period of interest is thought to be best described as lognormal, with SD of 10% in the first year of production, rising by 2% per year, and reaching 34% by the last year of production. This gives a roughly constant low price at about $10/barrel, with the high price rising from $23/barrel to $37.5/barrel through field life.[3]

Results from 10,000 Monte Carlo trials show the probability of a range of possible outcomes (previous page). The mean, or average, expected value is $124 million. That means a statistically significant number of identical opportunities would, on average, be worth $124 million each, in NPV terms.

But there is also a range of possible outcomes and a chance of very different results. For example, 10% of the cases run in the simulation gave values less than $27 million. Thus, the so-called P_{10} value of the outcome, or the value at which there is a 10% chance of the outcome being less than (or 90% chance of exceeding) is $27 million in this example. The lowest value given by any of the trials is –$112 million, and approximately 5% of the trials gave negative NPVs. On the other hand, the P_{90} was $223 million, so 10% of the trials gave values greater than $223 million.

For this particular field, there is a small chance, about 5%, of losing money, but a good chance of making a significant amount of money (for example, a 16% chance of making more than $200 million). The decision would probably still be to go ahead, but the Monte Carlo analysis, by revealing the broader picture, gives decision-makers greater comfort that their decision has taken everything into account.

Monte Carlo analysis is a powerful tool, but must be used with care (see "Monte Carlo Analysis of Interventions," *next page*). An error in assessing just one input, such as the range in oil price, can render the whole analysis defective. Thus, a Monte Carlo analysis of a North Sea field development in the 1980s might give a profoundly misleading picture if it was predicated on a range of oil prices that varied at or around the $35/barrel price that prevailed at the start of the decade. By the end of the 1980s, the price per barrel was $15 and below.

	Outcome	NPV, $ million	Independent probability, %
Safe	Dry hole	–10	40
	Success	50	60
Risky	Dry hole	–10	60
	Success	80	40

$ENPV_{Safe}$ = 60% x $50 + 40% x (–$10) = $26 million

$ENPV_{Risky}$ = 40% x $80 + 60% x (–$10) = $26 million

^ Comparison of hypothetical safe and risky E&P ventures. (Adapted from Ball and Savage, reference 4.)

Portfolio Theory

Most oil companies have many assets, such as fields, or shared interests in fields, and make every effort to assemble and hold the best possible combination of such assets. Portfolio theory shows how assets can be combined in such a way that risk is minimized for any given level of expected return. Alternatively, it may be seen as the study of the way in which the company can achieve a maximum rate of return from a portfolio of assets, each of which has a given level of risk attached to it.

The portfolio approach is based on the work of Harry Markowitz, who won the 1990 Nobel Prize for Economics for his theories on the evaluation of risk and reward in stock markets. Markowitz sought to prove that a diversified portfolio of financial assets, one that mixed assets so that return was maximized while risk was minimized, could be practical. Energy-risk analysts soon realized that there were parallels between the stock market, in which paper assets—stocks and shares—are traded, and the oil business in which companies hold and trade portfolios of real assets by, for example, buying and selling shares in joint ventures.

Portfolio theory can appear counterintuitive.[4] Imagine being responsible for investing $10 million in exploration and production projects. Only two projects are available, and each requires the full $10 million for a 100% interest. One project is relatively safe, and the other is relatively risky (above). The chances of success are independent.

3. The discount rate chosen is again 10%.

4. Ball BC and Savage SL: "Holistic vs. Hole–Istic E&P Strategies," *Journal of Petroleum Technology* 51, no. 9 (September 1999): 74–84.

Unconventional Risks

In the oil industry, risk and uncertainty models usually deal with wellbores and reservoirs. But similar models also can be used to explore the potential impact of more unconventional risks—political risks, terrorist threats, legal decision-making, environmental, health and safety regulations, and many others.

The approaches to modeling this sort of uncertainty use many of the mathematical techniques common to more traditional financial or physical risk analysis. However, many additional intangibles have to be defined before it is possible to properly frame the questions to be addressed by the risk model. Probabilities still have to be assigned, and, just as with physical and economic risks, a team of experts may be needed to develop appropriate distributions.

For example, in evaluating the political stability of a country in which a company wanted to operate, the risk team could set up probability distributions for possible governmental vulnerability, possible internal disorder, ethnic or religious problems, demographic pressures, or even possible war. With a proper combination and weighting of the variables, a Monte Carlo simulation could provide a cumulative probability plot of, for example, the total political risk in a country. This, in turn, could be compared with that of other countries to help the corporation make the appropriate strategic decision. A corresponding quantitative sensitivity analysis could also shed some light on the relative importance associated with the diverse risks.

In modeling unconventional risks, the modeler is attempting to quantify human activities and emotions, so the model can be only a rough guide. However, such models can generate data essential to the overall process of making an enlightened decision.

Monte Carlo Analysis of Interventions

A coiled tubing intervention program was proposed for a well in a mature North Sea field to remove a plug, isolate a watered-out layer and perforate an additional new producing zone. Previous experience suggested that a six-day job forecast for midwinter operations was overly optimistic because of the likelihood of bad weather increasing nonproductive time (NPT).

A model was needed to establish whether the initial projections provided were realistic and to determine how long such a job could run before it became uneconomic. It was assumed that the viability of the job would be determined by balancing the cost of doing it against the revenue generated from the additional oil produced, whether incremental (because access would be gained to otherwise untapped reserves) or accelerated (because accelerated production would provide a revenue stream earlier than would otherwise have been the case).

A model constructed to analyze the problem considered the following variables:

- oil price and lifting costs
- NPT due to weather and other operational-related downtime. This adds to the costs. Fixed costs of products and services did not vary.
- expected additional oil production after a successful job
- possibility of not completing the job successfully
- probability of correct diagnosis of the problem—including correct water influx location and mechanism
- discount factor.

The model was used to compute the net value of the intervention for 100 different job times. Each separate Monte Carlo simulation consisted of 5000 trials, resulting in 500,000 total separate trials. Results indicate that if the time to complete the job was only 20 hours, then there is a 50% likelihood (P_{50}) that the net value to the client would be £750,000 or more (the P_{90} is over £1 million). On the other hand, if the job were to take 100 hours, the model suggests that there would be only a 32% chance of profitability.

The analysis had several implications:[1]

- Reasonable working times for the job could be defined up-front.
- Sensitivity to various parameters is obvious.
- Prediction of additional oil had the greatest impact.
- NPT had the second greatest impact.

The analysis showed that the initial projection of six days for the job was overly optimistic and that the job was likely to yield a net loss. The results were used to define an alternative water shutoff proposal and a brief study to better understand additional production potential.

1. This model simplifies reality by assuming the independence of some of the variables. In more complex analyses, interdependences can be accommodated using so-called Markov chain Monte Carlo (MCMC) methods. The Markov chain Monte Carlo analysis method properly represents the interdependences of variables that would normally be treated as independent or otherwise correlated to others using correlation coefficients during Monte Carlo sampling. In MCMC calculations, the value of one variable impacts the probability distributions of the other variables. There are classes of problems in the oil industry, such as evaluating electrical submersible pump failures, that are thought to be solvable only with MCMC methods.

The expected net present value (ENPV) of each, which is the NPV of the successful outcome multiplied by the probability of that outcome occurring plus the NPV of the unsuccessful (dry hole) outcome and the probability of it occurring, is the same: $26 million.

Realistic complications now can be added. If money is lost, shareholder confidence tumbles. There is a 40% chance of losing shareholder confidence with the safe project and a 60% chance with the risky one. The ENPV for both is $26 million, so there is no way of increasing that by choosing the risky over the safe project. Under the circumstances, the safe project is obviously the better choice.

Adding a further complication, suppose it is possible to split the investment evenly between the two projects. Intuitively it would seem a bad idea to take 50% out of the safe project and put it into the risky one. But is intuition a good guide? There are now four possible outcomes (next page, top).

The expected NPV is still $26 million, but the only way to lose money and thereby forfeit shareholder confidence is to hit two dry wells—scenario 4—for which the combined probability is 24% (combining 40% x 60%). That cuts the risk of forfeiting shareholder confidence by almost half, compared to investing 100% in the safe project. Moving money from a safe project to a risky one actually reduces risk—a counterintuitive result, that represents the effect of diversification.

Diversification is clearly the thing to do; yet many in the oil industry persist in doing something else. They rank exploration projects by

Scenario	Safe	Risky	Probability, %	Return, $ million	Result
1	Success	Success	60 x 40 = 24	50% x $50 + 50% x $80 = $65	Shareholders' confidence retained
2	Success	Dry hole	60 x 60 = 36	50% x $50 + 50% x (–$10) = $20	Shareholders' confidence retained
3	Dry hole	Success	40 x 40 = 16	50% x (–$10) + 50% x 80 = $35	Shareholders' confidence retained
4	Dry hole	Dry hole	40 x 60 = 24	50% x (–$10) + 50% x (–$10) = –$10	Shareholders' confidence lost
ENPV of portfolio = 24% x $65 + 36% x $20 + 16% x $35 + 24% x (–$10) = $26 million					

^ Portfolio approach to hypothetical safe and risky ventures. Four scenarios show the possible outcomes from investing equally in two projects. (Adapted from Ball and Savage, reference 4.)

expected present worth. While this method uses common sense, it ignores the benefits of diversification. In the above example, this would have led to allocating all the funds to the safe project, with nearly twice the risk of the best portfolio.

The example makes one major assumption—that the projects are independent. Often they are not. Their outcomes may be interrelated, more formally known as statistically dependent. For example, if both projects involve drilling wells in the same hydrocarbon source area, a lack of hydrocarbon generation in the area would doom both endeavors. The simplest example of statistical dependence is correlation, which may be either positive or negative. The correlation is positive when a given outcome for one project increases the chances of an outcome in the same direction for the other, thereby diminishing the effect of diversification. It is negative when a given outcome for one project decreases the chance of an outcome in the same direction for the other, thereby enhancing the effect of diversification.

Applying this to the above example, a positive correlation on a 50-50 split between the safe and risky alternatives would mean that if the safe option succeeds, the risky one is also more likely to succeed, and if the safe project fails, the risky one is more likely to fail. There is still a 40% chance that the safe project will fail, but if it does, the chance that the risky one fails will be greater than 60%. So the probability of losing shareholder confidence is now more than 24%. Following the same logic, if the correlation is negative, the probability of forfeiting shareholder confidence drops to below 24%.

The goal in portfolio management is to spread the investments across many opportunities while seeking out negative correlations and avoiding positive ones. Statistical dependence can come from a variety of sources, including, for example, place and price. The economic outcomes of two sites close to one another may be positively correlated through geological similarities, such as draining the same reservoir rock or relying on the same hydrocarbon source or sealing rock. Two widely separated sites, on the other hand, would have little or no geological correlation and would therefore be more diversified.

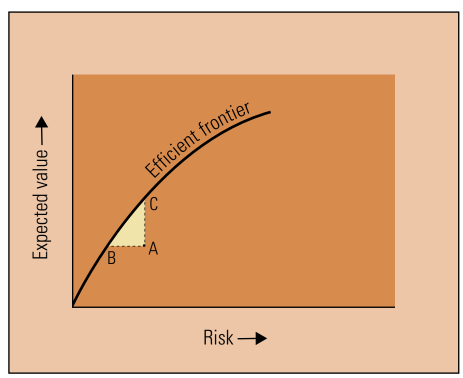
Crude-oil prices tend to be similar around the world, so the economic outputs of oil projects are positively correlated relative to fluctuations in crude prices. By contrast, natural-gas prices in different locations tend to track neither crude-oil prices nor each other very well. This means a portfolio consisting of a gas project and an oil project would tend to be less positively correlated and better diversified than a portfolio containing two oil projects.

A method for changing a suboptimal portfolio to a good one is explained in Markowitz's theory, which is based on three precepts.[5] First, the rational investor will choose more value over less value given a constant level of risk, but will also prefer less risk to more risk given a constant value. Second, there is more than one optimal portfolio. Third, the portfolio as a whole is more optimal than its individual projects. Each project must be considered based on what it brings to the portfolio as a whole.

Markowitz says that a portfolio is efficient if there isn't another portfolio that has a greater expected return with no more risk, and there isn't another portfolio that has less risk with no less expected return. If one or both of these conditions are false, the portfolio is inefficient. When all portfolios are plotted on a graph in which the vertical axis is value and the horizontal is risk, the efficient portfolios form a line called the efficient frontier (below).

Moving up the frontier line results in an increase in both risk and return. The portfolio represented by Point A is inefficient because there are portfolios with the same value but less risk—Point B—and portfolios with the same risk but more value—Point C—as well as portfolios with a combination of these two conditions.

5. Markowitz HM: *Portfolio Selections: Efficient Diversification of Investments*, 2nd ed. Oxford, England: Blackwell Publishing Company, 1991.



> Making a portfolio efficient. The aim is to assemble and exploit the best possible collection of assets. A portfolio is efficient if no other portfolio has a greater expected return with no more risk, and no other portfolio has less risk with no less expected return. Portfolios, like that represented by Point A, are inefficient. For the level of risk they involve, there is a possible combination of assets that would result in a higher expected value. (Adapted from McVean J: "Monte Carlo: An Alternative Approach to Efficient Frontier," http://www.merak.com/news/documents/ef-0399.html.)

Actual constraints can be included in the optimization process so that the portfolios on the resulting efficient frontier represent realistic alternatives from which management can choose, depending on the trade-off they wish to make between higher risk with higher return and lower risk with lower return (see "A System for Evaluating Exploration Projects," *below*).

Options Theory

An important aspect of decision-making is timing, or deciding "when" to decide. Conditions and input information can change over time, altering the outcome if decisions are made at different points.

Many oil companies—three-quarters of the Aberdeen sample—use decision trees as an aid to decision-making (next page). Decision trees illustrate the choices available, the uncertainties faced by the decision-maker and the estimated outcomes of each possible decision. These trees clarify the choices, risks, objectives, monetary gains and information needs involved in investment decisions.[6] Putting in an estimated value for each possible outcome and a judgment of the probability of each of those outcomes occurring allows the calculation of an overall risked value of the outcome of the decision.

Decision trees enable the decision-maker to choose based on the financial outcome of the options. Options theory, more properly known as the theory of real options, enables a value to be assigned to the option itself. Options theory builds on the idea that most projects consist not of "all or nothing" decisions but of a sequence of choices, many of which involve choosing among options—for instance, between investing money now in a development or postponing the decision on whether to invest in the development until further information becomes available.

The traditional way of evaluating investment projects in the oil industry, the discounted cash flow (DCF) analysis reviewed earlier, is based on the unrealistic assumption that once an investment is made, it runs its course without intervention. It also evaluates only the successful outcome. The possibility of abandoning it in the face of adverse circumstances or expanding it in response to unanticipated demand is not considered. Options theory is more sophisticated than DCF because it captures the flexibility inherent in most projects. Options theory is both a tool, like DCF, and a mind-set. As a tool, it helps people make decisions. As a mind-set, it pushes people into thinking about projects in a much more dynamic way, constantly looking for alternatives and better ways to run projects.

The theory of real options draws parallels between the financial world of stocks and bonds and the world of real physical assets, which might be anything from factories to oil fields. In finance it is possible, for a fee, to buy an option, which is the right (but not an obligation) to buy or sell a financial security such as a share at a specified time in the future at a fixed price. An option to buy is known as a "call" option and is usually purchased in the expectation that the price of the stock will rise. Thus a call option may allow its holder to buy a share in Company ABC for $500 on or before a set date. If the price of the stock rises above $500 on or before that date, the holder of the option can exercise it and pocket the difference. A "put" option is bought in the expectation of a falling price and protects against such a fall.

6. Newendorp PD: *Decision Analysis for Petroleum Exploration*. Tulsa, Oklahoma, USA: PennWell Publishing Company, 1996.
7. Black F and Scholes M: "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy* 81 (1973): 637-654.

A System for Evaluating Exploration Projects

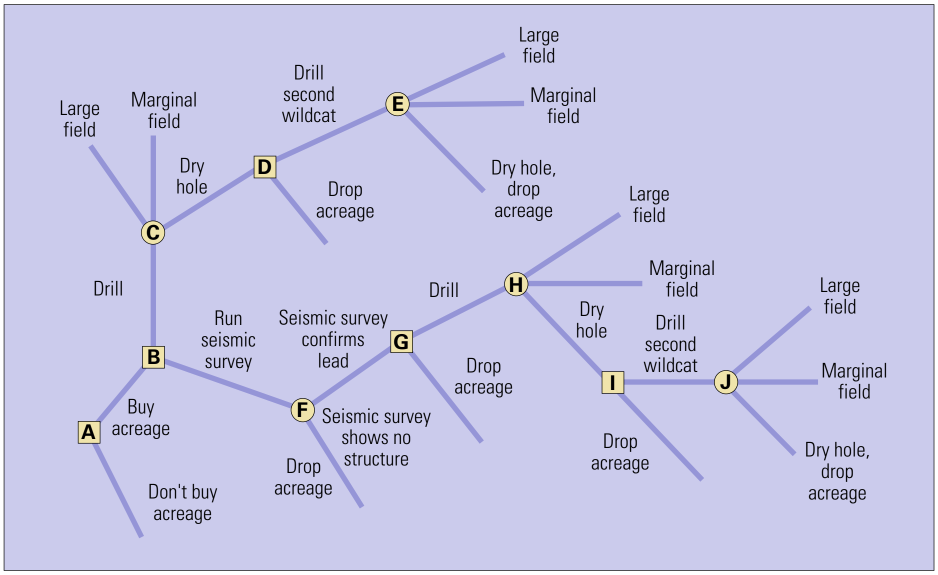
Chevron has developed a process that enables management to compare a wide variety of global exploration opportunities on a uniform and consistent basis.[1] The process includes the integration of geologic risk assessment, probabilistic distribution of prospect hydrocarbon volumes, engineering development planning and prospect economics.

The process is based on the concept of plays and hydrocarbon systems. A play is a combination of reservoir, source, seal and trap geometry that has the potential to contain hydrocarbons. Geologic risk assessment, volumetric estimation, engineering support, economic evaluation and postdrill feedback are all considered extensions of the fundamental knowledge and understanding of the underlying geological, engineering and fiscal constraints.

A foundation is set, describing the geologic framework and the prospect in terms of the play—source, reservoir, trap and seal, and the timing and dynamics of fluid migration. The information from this description becomes the basis for subsequent steps in the process. Risk assessment assigns a probability of success to each of these four elements of the play, and multiplication of these probabilities yields the probability of geologic success. Chevron considers a well a geologic success if a stabilized flow of hydrocarbons is obtained on test. Volumetric estimation expresses uncertainty in the form of a distribution of possible hydrocarbon volumes for the prospect. This is constructed from ranges of parameters obtained from information specific to the prospect, and data described by the parent play concept.

With this distribution, engineering support provides development scenarios for three cases—a pessimistic case (10%), the mean (50%), and an optimistic case (90%). Economic evaluation is run for each of the three cases, providing a range of economic consequences of the geological, engineering and fiscal framework. Commercial risk is based on the results of this evaluation, and overall probability of success is the multiplication of the probability of geologic success and probability of commercial success. Postdrill feedback determines whether predicted results are consistent with actual outcomes.

1. Otis RM and Schneidermann N: "A Process for Evaluating Exploration Prospects," *AAPG Bulletin* 81, no. 6 (July 1997): 1087-1109.



^ Decision trees for decision-making in uncertain conditions. A decision tree sets out alternative courses of action and the financial consequences of each alternative, and assigns a probability to the likelihood of future events occurring. With this information, it is possible to determine the expected value of each outcome. Decision-makers use decision trees to clarify the consequences that alternative courses of action may have. Decisions are shown as branching points, or nodes, in the tree. Each possible outcome is shown as a branch. Decision trees can be simple with only a small number of branches and nodes, or complicated with many of them. (Adapted from Newendorp, reference 6: 117.)

Real options are analogous to financial options. For example, if the oil company decides not to develop an oil field today, it can do so in the future. By paying a fixed license fee to the government, the company buys a real option: the right to realize payoffs at any time during the license term by making a further investment to develop the field, but with no obligation to do so—analogous to the exercise price of a call option.

The existence of alternative courses of action, such as to develop in the future rather than right away, is valuable. The flexibility gives the project a value that cannot be reflected in a static DCF analysis.

Because oil industry projects tend to consist of a sequence of discrete stages—seismic surveys, drilling, building the platform and laying pipelines, production, and ultimately, decommissioning—there are many decision points along the way. There may be several options to choose from and several opportunities to capitalize on that flexibility (see "Framing the Problem," *right*).

In 1973, economists Fischer Black and Myron Scholes published the so-called Black-Scholes formula for the valuation of financial options.[7] Some theorists argue that adaptations of the Black-Scholes formula and other more sophisticated formulas can be used to value real options—to make valuations that, unlike DCF, fully value flexibility. Using a valuation formula, the project can sometimes be shown to have a value significantly greater than that shown by DCF analysis. Projects that would have been rejected by managers using DCF analysis because they have a negative value can sometimes be shown, by real options valuation, to have a positive value that suggests the project should proceed.

Take, for example, an oil company that is trying to value its license in a block. Paying the license fee is equivalent to acquiring an option. The company now has the right to invest in the

Framing the Problem

Techniques like Monte Carlo simulation and options theory promise more accurate evaluation and better decision-making, but they are useless if the ground has not been properly prepared. If decision-makers miss something important in a contract or misunderstand an engineering point, then the whole superstructure of sophisticated analysis may be built on a faulty foundation.

In Conoco, the first critical step to effective decision-making is "framing." Framing involves establishing a team of people who are versed in the disciplines needed to tackle the problem, then using a facilitator to draw from these people crucial pieces of information, such as:

- what is known—facts and values
- what is not known—risks and uncertainties
- problems or difficult items
- what decisions have already been made—company policy.

Framing enables the team to concentrate on the key building blocks of the decisions to be made and the variables that will have the greatest influence. Framing sessions are conducted as informally as possible. The team's job is to make sense of the random flow of information captured as notes during the more rigorous later phases.

Framing facilitators use a variety of techniques, like brainstorming, to stimulate discussion. These generate decision hierarchies, decision and risk timelines and strategy tables. The final output of the framing session is an influence diagram, which forms the basis of any economic or technical model that is used to further examine the problem.

The framing process is a model of decision-making itself: start by thinking as widely as possible, distill the information, sift through the options and make a decision. Framing tackles the first two elements and can sometimes lead to the final decision without further analysis.

Training sessions on framing establish a common language for Conoco employees when talking about risk and help avoid the misinterpretations that may otherwise arise.

block at the exercise price once uncertainty over the value of the developed reserves—the stock price—has been resolved.[8]

Assume that the company has the opportunity to acquire a five-year license and that the block is expected to contain some 50 million barrels [8 million m^3] of oil. The estimated present value of oil from the field in which the block is located averages $10 per barrel, and the cost of developing the field (in present value terms) is $600 million. With static net present value calculations, the NPV will be:

$500 million – $600 million = –$100 million.

The NPV is negative, so the company would be unlikely to proceed. The NPV valuation ignores the fact that decisions can be made about the uncertainty, which, in this case, we consider to be twofold: there is uncertainty about the quantity of the oil in the block and about its price. It is possible to make reasonable estimates of the quantity of the oil by analyzing geophysical and geological data in similar areas, and there is also some historical data on the variability of oil prices.

Assume that these two sources of uncertainty result in a 30% standard deviation around the growth rate of the operating cash inflows. Assume also that holding the option obliges the company to incur the annual fixed costs of keeping the reserve active—say $15 million. This represents a dividend-like payout of 3% (15/500) of the value of the asset.

Applying the Black-Scholes formula, but this time valuing a real option rather than a stock option, gives a real options value (ROV) of +$100 million.[9] The $200 million difference between the NPV valuation of negative $100 million and the ROV valuation of positive $100 million represents the value of the flexibility of being able to invest if and when the uncertainties are resolved.

Calculations like this can have a powerful influence on how corporate strategists regard their assets. One company collected a large portfolio of North Sea license blocks. When the NPV of blocks was positive, the company drilled and developed them. When NPV suggested they were uneconomic because costs were too high in relation to revenues, development was not undertaken. The company eventually decided to sell the uneconomic blocks to companies that found them attractive.

Then the question arose whether the blocks were being valued in the right way. It was suggested that holding the license might be considered an option to develop, if, in the future, new drilling and production technologies would enable improved hydrocarbon recovery. A new financial model demonstrated how blocks could be priced at their option value over five years. The option value would recognize uncertainty in reserve size and oil prices, and would take into account the flexibility of the situation.

The valuation exercise had a profound effect on the company's management. They decided to retain the blocks that had a high option value and to sell or trade the rest at a figure that reflected their revised worth.

Preference, or Utility, Theory

People may use computers or decision tools like discounted cash flow or Monte Carlo analysis to help them, but in the end the decision is made by an individual or a group of people. Subjectivity complicates the decision-making process, since the individual's psychological makeup can influence decisions. In the oil industry, risk plays an important part in the thinking of executives. Understanding individual or group preferences and attitudes toward risk and risk-taking can be important.

In 1738, the mathematician Daniel Bernoulli published an essay in which he noted a widespread preference for risk aversion.[10] Nearly 250 years later, Daniel Kahneman and Amos Tversky gave a simple example of risk aversion.[11] Imagine you are given a choice between two options. The first is a sure gain of $80, and the second a more risky prospect in which there is an 85% chance of winning $100 and a 15% chance of winning nothing. According to Kahneman and Tversky, people prefer the certain gain to the gamble, despite the fact that the gamble has a higher "monetary expectation"—the sum of the outcomes weighted by their probabilities—than the certain outcome. With the certain outcome, one is assured of $80. With the riskier option, the monetary expectation would be $85 ($100 x 0.85 plus $0 x 0.15). The choice is risk-averse if one prefers the assured $80 to gambling on the riskier outcome (see "Risk Aversion," *page 32*).

Mathematician John von Neumann and economist Oskar Morgenstern expanded preference theory with a number of axioms that are paraphrased in the following statement:

Decision-makers are generally risk-averse and dislike incurring a loss to a greater degree than they enjoy making a profit of the same amount. As a result, they will tend to accept a greater risk to avoid a loss than make a gain of the same amount. Also, they derive greater pleasure from an increase in profit from a small investment than they would from the same profit increase from a larger investment.[12]

These statements can be expressed graphically as a utility curve (next page, far right). This example shows that the pleasure, or utility, associated with winning $4,000 is generally less than the displeasure of losing the same amount. People will take a greater chance to avoid a loss than to make a gain of the same amount. People also tend to feel more pleasure about gaining $10 by going from $10 to $20, than they do about gaining $10 by increasing from $1,500 to $1,510.

Theoretically, it is possible to draw such a curve for any individual or even a company. Curves with different shapes would denote different types of decision-makers (next page, right). The shape of the curve in the lower left-hand quadrant describes how the company feels about loss, and that in the upper right quadrant shows its attitude to risk and the levels of profit associated with risk.

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8. Leslie KJ and Michaels MP: "The Real Power of Real Options," *McKinsey Quarterly* no. 3 (1997): 4-22.

9. The value of a real option, P, is estimated by applying the Black-Scholes formula as follows:
$P = Se^{-\delta t} \times \{N(d_1)\} - Xe^{-rt} \times \{N(d_2)\}$,
where $d_1 = \{\ln(S/X)+(r-\delta+\sigma^2/2)t\}/(\sigma \times \sqrt{t})$,
$d_2 = d_1-\sigma \times \sqrt{t}$,
and where S = stock price, X = exercise price, δ = dividends, r = risk-free interest rate, σ = uncertainty of stock-price movements, t = time to expiration, and N(d) = cumulative normal distribution function.

   By analogy the value of a real option uses the same formula, but this time S = present value of expected cash flows, X = present value of fixed costs, δ = the value lost over the duration of the option, r = risk-free interest rate, σ = uncertainty of expected cash flows, and t = time to expiration.

   Substituting the values in the example discussed in the main text gives

   $ROV = (500e^{-0.03 \times 5}) \times \{(0.58)\} - (600e^{-0.05 \times 5}) \times \{(0.32)\}$
   = $251 million - $151 million = +$100 million.

10. Bernoulli D: "Specimen Theoriae Novae de Mensura Sortis," (Exposition of a New Theory on the Measurement of Risk) 1738, Translated from the Latin by Sommer L: *Econometrica* 22 (1954): 23-36.

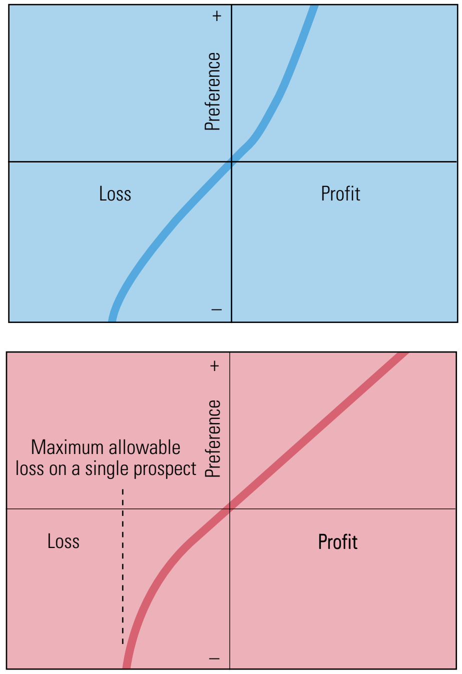
11. Kahneman D and Tversky A: "The Psychology of Preferences," *Scientific American* 246, no. 1 (1982): 160-173.

12. Pace B: "Petroleum Economics Seminar," lecture notes, Imperial College of Science, Technology and Medicine, London, England, 1998.

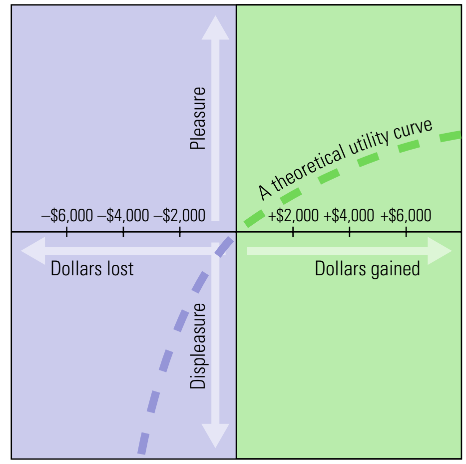
13. Simpson et al, reference 2.

It is possible, by analyzing the previous decisions of an individual or a company, to construct a utility curve that represents what the decision-maker thinks about risk, or rather how he or she reacts to its presence when making decisions. And such an instrument could, of course, be used to help guide decision-makers farther down the hierarchy in making decisions that fit with the thinking of the top management or the company as a whole.

In practice, few companies use preference theory to help in decision-making. Critics say the practical problems are just too great. Within the same organization, one manager may typically champion risky projects, while another in a similar position may be more conservative. Perhaps, rather than being used as a tool to help individuals or companies make decisions, preference theory does have a more limited but still important role. It can graphically demonstrate to decision-makers what their style of decision-making implies.



^ Utility curves representing different types of decision-makers. The utility curve for a risk-taker *(top)*, for example, might be represented by a sharp rise in the upper right quadrant showing that the attraction of big money overcomes the fact that there is obviously a disproportionate risk. A different utility curve for a large company *(bottom)* that accepts losses with equanimity is shown by the straight line. However, the sharp drop-off in the lower left quadrant makes it clear that there is still a maximum allowable exposure to loss. (Adapted from Pace, reference 12.)



^ Building a utility curve. A typical curve might purport to describe how an individual felt about gaining or losing money—usually the pleasure associated within winning a given amount is less than the displeasure associated with losing the same amount. [Adapted from Rose PR: "Dealing with Risk and Uncertainty in Exploration: How Can We Improve?" *AAPG Bulletin* 71, no. 1 (1987): 1-16.]

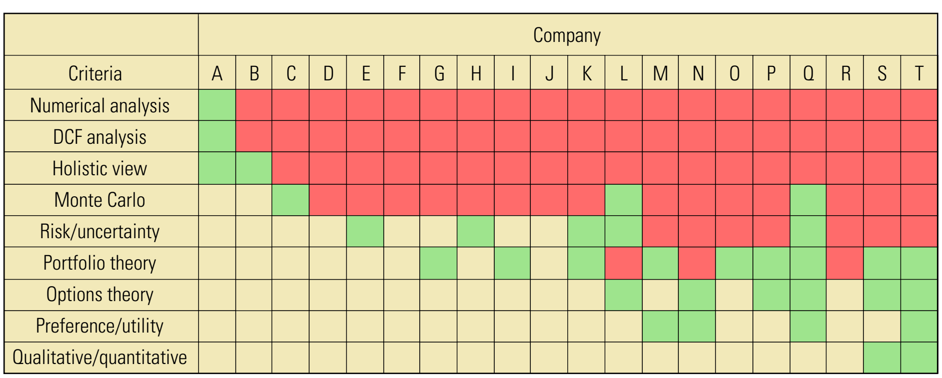
The Value of Risk Assessment

Is it possible to quantify the value gained by using these tools? This was the objective of the Aberdeen study mentioned earlier in this article. The Aberdeen study ranked the participating companies according to the level of sophistication of their decision-making (below). The levels included the risk-assessment tools described in this article and others such as analysis, holistic view, risk and uncertainty definitions, and the combination of qualitative and quantitative techniques.

"Analysis" refers to the use of some form of cost-benefit analysis in investment appraisal decision-making. All but one company used some structured analysis. "Holistic" indicates whether or not a company takes a holistic view of the total cumulative net effect of the consequences of a decision. For example, any upstream decision must include abandonment of facilities and the cost and timing implications of any environmental protection measures that need to be taken.

"Risk and uncertainty" indicates whether the company adopts rigorous definitions of risk and uncertainty, and incorporates them in their analysis. Risk, here, is defined as the probability of an event occurring. Uncertainty is the range of possible values for the size, cost and benefits of an event, if it happens. The category "qualitative and quantitative" indicates whether companies have formal techniques to deal with qualitative as well as quantitative input—things such as habit, instinct and intuition.[13]

These criteria were arranged in ascending order of sophistication. Companies scored zero if they did not use a particular risk-assessment method; they scored 1 if the method was partially implemented; and scored 2 for full implementation. The scores were summed to rank the level of sophistication of the companies. The researchers also ranked the companies by several business performance measures.



^ Ranking companies by their level of decision-making sophistication. Research done at the University of Aberdeen showed that the decision-making practices of 20 companies (labeled A to T) active in the North Sea correlate well with the success of their investment decisions. Companies scored highest (red) if they fully implemented the decision-making criteria shown in ascending order of sophistication in the left column. If the criterion was partially implemented by the company, a green square is indicated in the chart. Uncolored squares indicate that the company did not use the particular risk-assessment method.

Risk Aversion

A recent study by the Colorado School of Mines (CSM) in Golden, Colorado, examined the risk-taking behavior of 40 of the top US-based oil companies over the 15-year period from 1981 through 1995.[1] The researchers' starting point was the fact that when decision-makers are judging a potential investment, they are aware not just of the risks involved but of the amount of the company's capital that is being exposed to the chance of loss. Economists usually have assumed that the degree of risk aversion decreases as wealth increases, and that as a company becomes wealthier, it is more prepared to take on larger, riskier projects. A small company that is offered a risky project in which the upside is significant profit but the downside is a loss that would swallow up a big chunk of the company's capital may reject it. But a larger company, for whom the downside might not represent such a large proportion of its resources, might accept the project.

The CSM researchers used the concept of the risk tolerance ratio (RTR) to compare companies. The RTR is a ratio of the company's observed risk tolerance, RT, (a number derived by mathematics beyond the scope of this article) divided by its predicted risk tolerance. An example shows how the RTR works (top right). For any firms i, the RTR_i value is equal to RT_i/RT_i' where RT_i is the observed risk tolerance for firm i in period t and RT_i' represents the predicted risk tolerance of firm i as a function of size measured by the standardized measure of discounted future net cash flows (SMCF) for that same period. An RTR value greater than 1.0 implies a stronger propensity to take risk than do other firms of equivalent size. An RTR value less than 1.0 implies a weaker propensity to take risk than firms of equivalent size.

Risk tolerance ratios were calculated for the top 17 US oil companies over the period 1983 to 1995 (below). Compare Exxon and Shell in 1988. Exxon had an RTR of 0.87 while Shell's was 2.76. This suggests that Exxon was significantly less willing to take risks than firms of equivalent size, while Shell was an aggressive risk taker compared with other companies of similar size.

The study defined four categories of risk taking (above right). Firms in the high-risk tolerance category (more than 2.5) show significantly higher return on assets (8.6%) than firms that are less willing to take risks. Firms in the other categories have exercised risk-averse behavior and get much lower returns on their assets. The CSM study suggests that, on average, companies in the exploration business tended to be too cautious with respect to risky projects and as a result have realized lower return on assets than they might otherwise have done.

	Operator 1	Operator 2	Operator 3
$SMCF_i$ (wealth)	$1,000 million	$100 million	$10 million
RT_i' (predicted)	$100 million	$15 million	$2 million
RT_i (actual)	$50 million	$20 million	$2 million
RTR_i (RT_i/RT_i')	0.50	1.33	1.0

^ **Estimating risk tolerance ratios (RTR). An RTR value greater than 1.0 implies a stronger propensity to take risk than firms of equivalent size. An RTR value less than 1.0 implies a weaker propensity to take risk than firms of equivalent size.**

RTR group	High	Moderate	Average	Low
RTR	> 2.5	1.5 to 2.5	0.5 to 1.5	< 0.5
Maximum	28.1%	24.2%	32.0%	20.9%
Minimum	–5.5%	–34.2%	–37.0%	–25.8%
Mean	8.6%	5.2%	5.1%	5.6%
St. Dev.	6.8%	9.3%	8.7%	5.5%

^ **Performance analysis—return on E&P assets. Firms in the high-risk tolerance category show significantly higher return on assets (ROA) than firms that are less willing to take risks.**

1. Walls M: "Corporate Risk Taking and Performance: A 15-Year Look at the Oil Industry, paper SPE 49181, prepared for presentation at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, September 27–30, 1998.

Company	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	1995 E&P assets, $ million
Exxon	1.03	0.83	1.58	1.00	0.75	0.51	0.50	0.87	0.65	0.76	0.47	0.63	1.07	68,852
Chevron	0.17	0.31	0.46	0.48	0.64	NA	NA	1.24	0.43	0.35	0.29	0.39	0.90	27,913
Texaco	NA	1.81	1.47	1.26	0.95	0.74	8.82	0.76	0.72	0.56	0.41	0.94	0.48	18,734
Amoco	0.21	0.49	0.71	0.44	0.29	0.12	0.36	0.55	0.48	0.28	0.33	0.44	0.41	15,241
Mobil	0.83	1.06	1.74	1.91	NA	5.89	0.70	0.46	0.29	0.27	0.16	0.23	0.32	14,393
Shell	0.80	1.33	1.15	1.85	2.33	2.58	2.39	2.76	1.64	1.70	1.86	1.82	2.19	11,976
USX	0.65	0.46	0.42	10.08	0.36	0.45	0.38	0.79	0.66	0.63	0.25	0.38	2.64	10,109
Arco	1.00	4.63	3.13	1.49	1.41	1.23	0.96	1.31	1.38	1.75	1.02	0.90	1.35	9,127
Conoco	1.44	2.41	2.82	2.36	3.26	3.31	3.05	3.77	3.64	2.86	2.38	NA	NA	6,649
Phillips	1.92	1.37	1.81	1.97	2.80	1.85	3.23	NA	NA	1.62	1.26	1.41	1.55	4,828
Unocal	5.22	NA	1.92	2.01	2.92	1.96	1.97	3.48	1.83	NA	NA	NA	NA	4,719
Occidental	1.39	2.61	2.58	NA	2.91	3.32	2.15	2.39	2.49	1.92	1.75	1.40	4.36	4,594
Amerada	0.95	2.18	2.79	0.69	NA	NA	6.99	0.95	1.10	NA	0.78	0.73	1.18	3,873
Anadarko	NA	1.57	1.29	2.05	2.00	2.80	0.74	1.16	1.27	1.87	1.64	2.12	NA	2,267
Pennzoil	0.22	0.50	0.67	NA	0.38	0.27	0.44	0.83	NA	NA	NA	NA	NA	1,992
Kerr McGee	NA	2.98	NA	NA	1.74	0.97	4.08	1.42	1.75	1.39	1.54	0.92	2.14	1,748
Uniontex	NA	NA	NA	NA	NA	0.84	2.43	2.80	1.25	1.83	1.46	3.34	4.41	1,695

^ **Risk tolerance ratios for different companies between 1983 and 1995.**

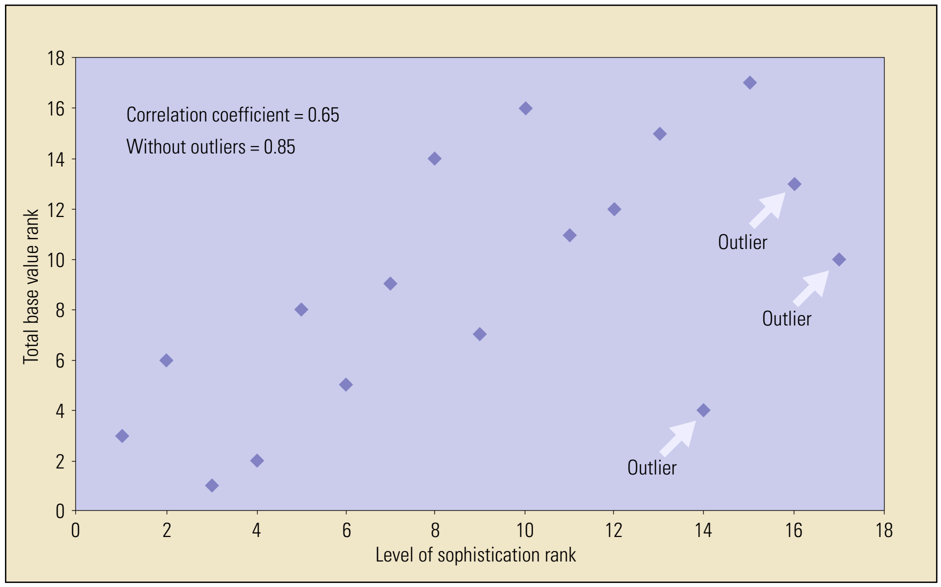
Five indicators of success were considered. First, market capitalization indicated the investment community's view of the future value of the company's ability to make wise investment decisions. Second, the number of employees served as a rough indication of both past success and anticipated future success in selecting and gaining access to the best investment opportunities. Third, the volume of booked reserves was used as a proxy for size and as an indicator of past success in investment decision-making. Fourth, return on equity indicated past successful decision-making. Fifth, Wood Mackenzie's estimate of the company's total UK base value (value of commercial reserves + value of technical reserves + value of exploration) was used as an indicator of successful past investment decision-making.[14]

The outcome was a strong positive correlation between the ranking positions of companies on the decision-making scale and their positions in the rankings for total base value, market capitalization and proven reserves. The correlation with number of employees was modest and that between decision-making and return on equity weak. The return on equity figure did not surprise the researchers. This measure relates strongly to historical decision-making—decisions made 15 or 20 years ago—while in most companies the current practice in decision-making is recent, usually less than five years old. By contrast, the measures of volume of booked reserves and, particularly, total base value captured the effects of recent decision-making performance. The strong correlation between Wood Mackenzie's total base value and the level of sophistication rank list clearly demonstrated a link between sophistication of tools used and business success (right).

In addition to these correlations, the researchers found that while Monte Carlo analysis is used widely for prospect reserves—a clear recognition of the importance of uncertainty at this technical level—it is scarcely used at all for prospect economics.[15] The researchers suggest that this implies, in the cases of those who do not use it, an assumption of complete certainty in cost, product price, fiscal terms and timing parameters, clearly an invalid assumption. In addition, it is mainly the larger companies that use portfolio theory. The researchers found that some smaller companies are less likely to use portfolio theory, because they feel they have insufficient properties to constitute a "portfolio" (though the theory applies equally to just two properties).

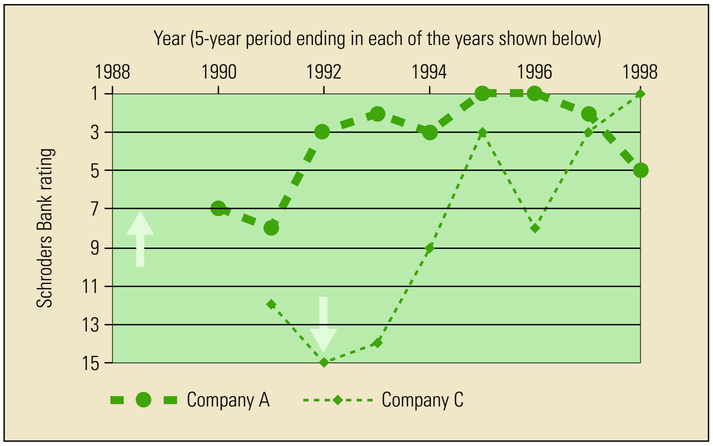
Since the Aberdeen findings were published, another group of risk experts sponsored by the Norwegian Petroleum Directorate and most exploration and production (E&P) companies active in Norway has published a research paper which, among other things, suggests that the use of probabilistic methods in the decision-making process is an important contributor to company performance.[16]

The researchers looked at different methodologies to describe the maturing of projects and the subsequent decision-making process. They found that although most companies appear to be technically capable of applying probabilistic models, only a few of them use these methods routinely in their decision-making process.

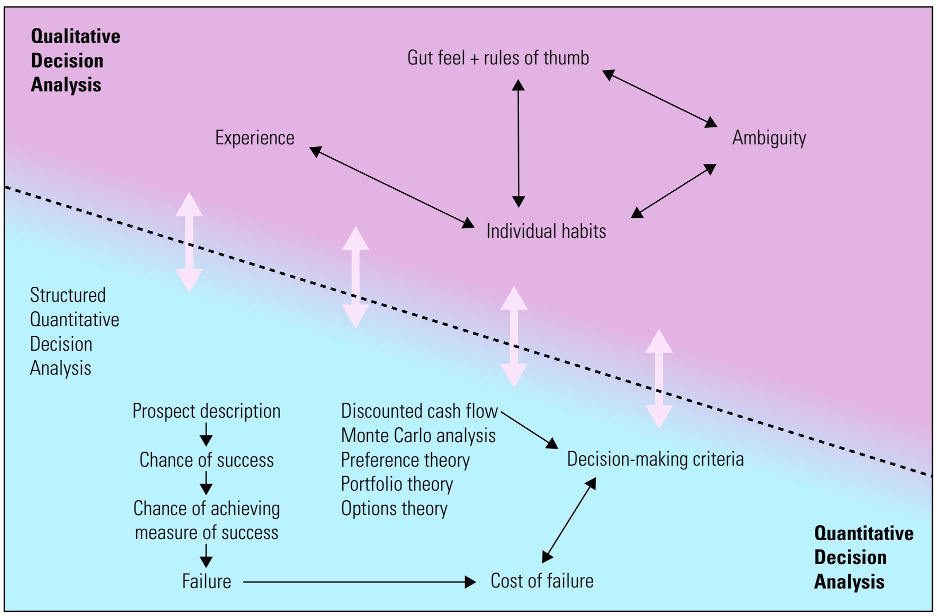


^ The correlation between level of sophistication in the use of decision-making tools and total base value (TBV). TBV is a measure devised by Edinburgh-based energy analysts Wood Mackenzie, which takes into account proved, probable and possible reserves and makes an attempt to value exploration acreage. The Aberdeen researchers believe TBV is a particularly good measure since it captures the results of decisions made in the recent past, and most sophisticated decision-making tools have been in use for a comparatively short time.

14. Simpson et al, reference 2.
15. Simpson et al, reference 2.
16. Jonkman RM, Bos CFM, Breunese JN, Morgan DTK, Spencer JA and Søndenå: "Best Practices and Methods in Hydrocarbon Resource Estimation, Production and Emissions Forecasting, Uncertainty Evaluation and Decision Making," paper SPE 65114, presented at the SPE European Petroleum Conference, Paris, France, October 24–25, 2000.



^ A benchmarking study of major oil companies listed on the New York Stock Exchange. Company performance, as rated by Schroders Bank, increased after decision and risk-analysis processes were introduced (white arrows).



^ Understanding the different sides of decision-making. The lower half of the figure (blue) shows how quantitative means, like discounted cash flow and Monte Carlo analysis, are used to analyze risk and make decisions. The upper half (pink) shows how qualitative means can be used for the same sort of analysis. There is often tension between the two (white arrows), as when executives follow their intuition rather than the figures. Researchers are now investigating how decision-makers make their decisions, looking at the softer, qualitative aspects of the decision. Once that is understood, the next step will be to find the linkage between them.

Among the most important of the methodologies studied was what the researchers called decision and risk analysis (D&RA), which includes elements of the various techniques described above. This was defined in the Norwegian study as a fully integrated, multidisciplinary probabilistic approach based on ranges for various parameters including field geology, reservoir properties (such as porosity), steel costs, manpower costs, facilities downtime and development scenarios. It also incorporates the propagation and aggregation of uncertainty through the various linked models and through the various decision levels.

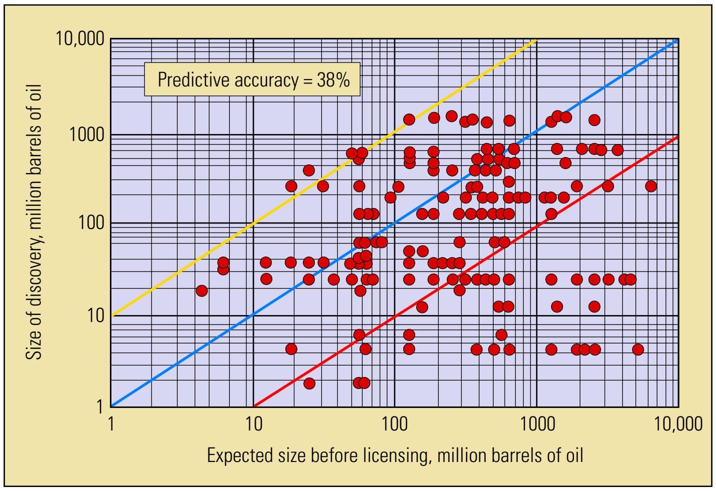
Using an economic benchmarking study of the major oil companies listed on the New York Stock Exchange, the researchers inferred a relationship between company performance and working practices (above left). Companies that integrated their workflow and used D&RA saw their performance improve shortly after the introduction of this methodology.

The Norwegian study claims that a fully probabilistic, multidisciplinary workflow according to a D&RA process influences a company's competitive position. There is also circumstantial evidence to support the contention that the more an E&P company integrates its workflow and the more probabilistic its approach in decision-making is, the better the company will perform.

17. Lamb FE, Simpson GS and Finch JH: "Methods for Evaluating the Worth of Reserves in the Upstream Oil and Gas Industry," *Geopolitics of Energy* 22, no. 4 (April 1999): 2-7.
18. Capen EC: "The Difficulty of Assessing Uncertainty," *Journal of Petroleum Technology* 28, no. 8 (1976): 843-850.
19. *The 1997 Annual Report of the Norwegian Petroleum Directorate*. Stavanger, Norway: Norwegian Petroleum Directorate Publications (1998).
20. Citron GP, Carragher PD, McMaster GM, Gardemal JM and Jacobsen D: "Post Appraisal and Archival: Critical Elements in Successful Exploration Risk Assessment," paper presented at the first Landmark Worldwide Technology Forum, Houston, Texas, USA, February 12–14, 1997.
21. Smith P: "Managing Uncertainty in Oil Field Developments: A Practical Guide to Making Better Decisions," paper presented at the Schlumberger Oil and Gas Decision and Risk Analysis Symposium, Austin, Texas, USA, November 20–21, 1997.
22. Simpson et al, reference 2.

    Carragher PD: "Leveraging Learnings from Exploration Risk," *AAPG 2000 Convention Abstracts*, Annual Meeting and Exhibition of the AAPG, New Orleans, Louisiana, USA (April 16–19, 2000): A23–A24.

    Jonkman et al, reference 16.



^ Recalibrating prospect forecasts. Operators in the Norwegian North Sea consistently have been overly optimistic when forecasting the size of prospects for inclusion in applications for a concession. The X-axis shows the size of expected prospects operators reported to the Norwegian Petroleum Directorate during the last ten years. The Y-axis shows the actual discoveries recorded. The central diagonal line (blue) represents a perfect calibration. The upper diagonal line (yellow) represents forecasts underestimated by a factor of 10. The lower diagonal line (red) represents forecasts overestimated by a factor of 10. The vast majority of all the forecasts fall below the central diagonal line, which by definition represents bias in the estimations of the operators. The sum of all the actual discovery sizes equals about 38% of the sum of the forecast discovery sizes. Only discovery data are included. (Adapted from *Discoveries on the Norwegian Continental Shelf*. Produced in collaboration with the Norwegian Petroleum Directorate: Stavanger, Norway, 1997.)

The Roles of Intuition and Bias

The processes described above do not constitute the complete story. While structured quantitative analysis is part of the standard decision-making process, qualitative intuition and judgment are extremely important (previous page, bottom). This model represents a view of the complete decision-making process, as seen by the Aberdeen researchers.[17] The interface between the quantitative and qualitative factors, and the relative proportions of each used in each decision are described in terms of an analogy with a geological feature called an angular unconformity.

The vertical axis of the model represents the type of decision being considered, with higher level decisions (for example, whether or not to enter a new basin or country, or to take over another company) fitting in the top half of the model, and more operational, routine decisions falling in the lower half.

The position along the horizontal axis relates to company culture; some companies rely primarily on quantitative "hard" analysis with very little "gut feel" input, and therefore would be positioned on the left side of the model. Other companies are the reverse. This perhaps explains some of the problems experienced when making decisions in partnerships and alliances when the various partners may occupy significantly different positions on this axis. This model of decision-making in the upstream oil and gas industry seems to fit well with the experiences and practices of those working in the industry. However, no significant correlation has been found between a company's position in the model and its business success. It is a question of fit: each company works best where it is culturally most comfortable.

There is also a link between the structured quantitative and the unstructured qualitative input: the decision-maker's qualitative judgment influences the numbers that go into the quantitative analysis. For any of the tools described above to be truly useful, the required geotechnical and financial inputs must be reliable. But where do such numbers come from? To start with, almost all of the geotechnical inputs and many of the financial ones represent estimates made. Increasingly, the E&P industry is recognizing the need to express such estimates as probabilistic ranges, rather than single "best-guess" values, but there is strong evidence of pervasive and substantial bias in exploration and production project estimates:

- The predictive ranges of key parameters are far too narrow—uncertainty is underestimated.[18]
- Discovered fields typically contain only about 40% of the oil and gas volumes that were predicted prior to exploration drilling (left).[19]
- High-risk prospects fail about four times more often than predicted because risk is underestimated.[20]
- Actual well costs often exceed forecast costs by 20 to 100%.
- Economic projections and yardsticks used to measure and rank ventures are often uncalibrated, being only infrequently compared with actual outcomes.

On worldwide projects, one major oil and gas company reported the following actual versus predicted measures: capital expenditure overruns averaged 95%, with a maximum of 974%; operating expenditure overruns averaged 140%; first-oil production starting between one and three years later than predicted; and average production rates 65% of those predicted.[21]

Correcting predictive bias is an organizational problem, related to people, incentive systems, consistent procedures, corporate culture and leadership. It is not primarily a technology problem, although new technologies can help reduce bias. Another aspect of the bias problem deals with preferred styles of decision-making. Executives, who may have succeeded through their intuitive, subjective decision-making style may be understandably reluctant to begin relying on a probabilistic, systematic portfolio-management style.

Several recent independent studies tell the same tale: integrated, probabilistic, systematic, centrally coordinated management of exploration and production portfolios produces better performance than traditional methods.[22] Most of the systematic, probabilistic companies work hard to minimize predictive bias, and they track past predictive performance in order to improve it. Unbiased forecasting is a recognized objective.

The risk-analysis tools discussed have real and enormous potential for improving exploration and production performance. But the human part of the equation must be improved if this potential is to be fully realized. —MB, RH