Making Decisions in the Oil and Gas Industry

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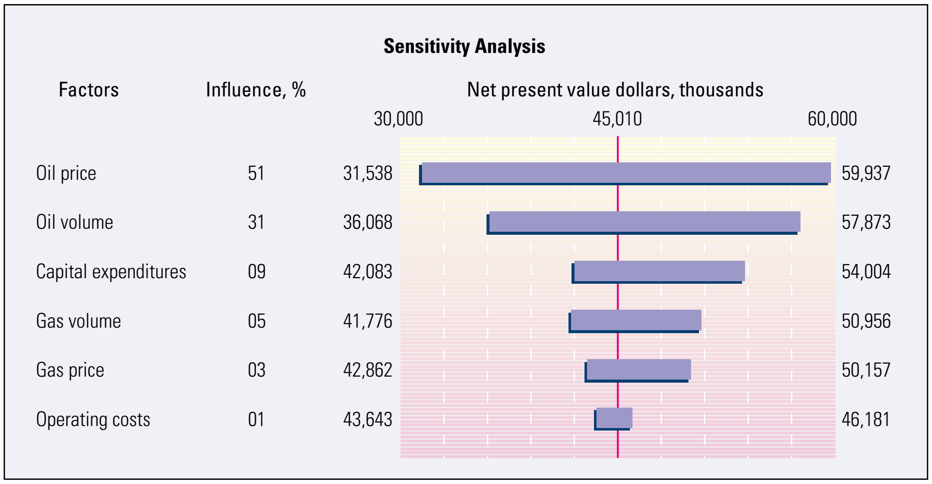
The difference between a good decision and a bad one can be the difference between success and disaster, profit and loss, or even life and death. Decision-analysis software can help decision-makers identify factors that influence the decision at hand and choose a path to desirable outcomes.

Decisions in the oil and gas industry determine the direction and course of billions of dollars every year. The complexity of a decision can range from simple and Shakespearean—to drill or not to drill—to elaborate. Some of the more monumental decisions determine the maximum bid for a lease, the best development process for a given asset, the drilling priority of a company's exploration opportunities, the timing of increasing facility capacity, or whether to sign a long- or short-term supply contract.

While simpler problems may be analyzed with a few quick calculations, reaching more complicated decisions can take a company months or years of preparation. For example, one of the dilemmas challenging E&P companies today is how to develop deepwater prospects. Sometimes subsea development is best; sometimes a tethered floating structure is the solution. Typically, oil companies spend 12 to 18 months in the decision cycle—gathering information, analyzing data and modeling risk and uncertainty—before selecting a production system. Streamlining this process may increase profit by shortening the time to first production.



^ Tornado plot showing factors that most influence a decision. Of the six factors selected for analysis, oil price and oil volume have the highest range in net present value (NPV), making the outcome most sensitive to those factors.

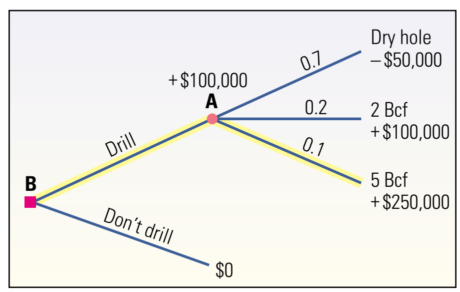
Several methods are available to help decision-makers evaluate uncertainty, reduce risk and choose workable solutions.[1] These methods include net present value (NPV) calculations, discounted cash-flow analysis, Monte Carlo simulation, portfolio theory, decision-tree analysis and preference theory—all of which were reviewed in a recent *Oilfield Review* article.[2] Elementary situations can be solved with basic expected-value computations, but more involved cases require a decision-analysis process that combines information from multiple disciplines, allows for uncertainty and evaluates the impact of different decisions. This article focuses on decision-tree analysis and how it works, as demonstrated through two case studies.

Decision-Tree Analysis

Decision-tree analysis is one way to frame and solve complex situations that require a decision. The key to obtaining a useful solution is to clearly define the problem at the start and determine what decisions need to be made. The problem-definition stage includes identifying all known information and listing any factors that may influence the final outcome. To expedite the process, decisions that can be deferred are postponed so that future information can aid the decision process.

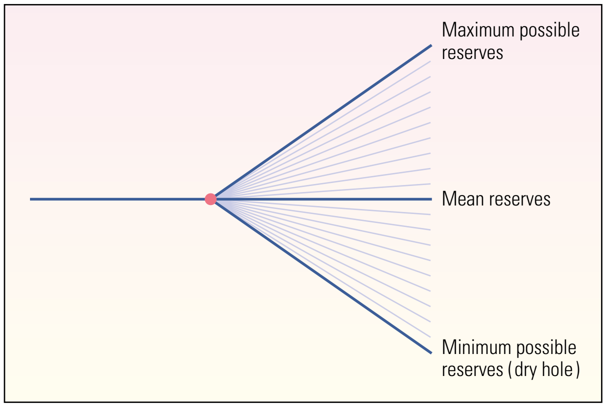
Capturing the essence of a problem by determining which are the influential factors helps decision-makers concentrate on only those issues that play a major role in the outcome. Such sensitivity analysis prioritizes the importance of factors to be considered in a decision. For example, one decision may depend on six factors: oil price, oil volume, gas price, gas volume, capital expenditures and operating costs—but the relative importance of these is unknown. For given uncertainties, or a range of possible values, for each factor, sensitivity analysis calculates the net present values (sometimes written as after-tax cash) represented by those uncertainties and ranks each factor (left).[3] The factors that most affect project outcome are the ones with the highest NPV range. The shape of the graph, with large values on the top and small values on the bottom, gives it the name "tornado plot." In this example, the two most important factors are oil price and oil volume. Operating-cost uncertainty does not significantly affect the outcome, and so can be treated as a certainty without markedly affecting the results.

Once the problem is framed, decision trees help find a route to an advantageous solution. Decision trees are diagrams that portray the flow of a decision-making process as a sequence of events and possible outcomes (below). Events are represented as points, or nodes, and outcomes are depicted as branches issuing from each node. Nodes are either decision nodes—at which the decision-maker determines what branch to take—or uncertainty nodes, where chance rules the outcome.[4] Associated with each branch is the expected monetary value of the outcome. Additionally, branches emanating from uncertainty nodes are weighted by the probability of that outcome occurring. In common notation, decision nodes plot as squares and uncertainty nodes as circles.



^ Simple decision tree showing one decision node (square) and possible outcomes. Outcomes are labeled with their expected value multiplied by the probability of that outcome occurring. The path with the highest expected value is highlighted in yellow. (Adapted from Newendorp, reference 1.)

1. Newendorp PD: *Decision Analysis for Petroleum Exploration.* Aurora, Colorado, USA: Planning Press, 1996.
2. Bailey W, Couët B, Lamb F, Simpson G and Rose P: "Taking a Calculated Risk," *Oilfield Review* 12, no. 3 (Autumn 2000): 20-35.
3. Net present value is one possible value measure, but many others can be used, including rate of return and profit-to-investment ratio.
4. Newendorp, reference 1, chapter 4.



^ Continuous distribution of expected reservoir size. Although the expected value of the reservoir size can fall anywhere in the continuous distribution, the most likely values should be selected for the decision-tree branches. (Adapted from Newendorp, reference 1.)

In this simple example, the decision node marks where the decision-maker elects to drill or not to drill. The expected value associated with a decision not to drill is $0; that is, no money is spent or gained. The value expected from the decision to drill depends on what is encountered downhole: there is a 10% chance of 5 Bcf of gas, a 20% chance of 2 Bcf, and a 70% chance of a dry hole. The expected reservoir size is in fact a continuous distribution rather than three-valued, but for the purpose of this example, three sizes are examined (above). Ideally, branches of the uncertainty node try to capture the most important aspects of this continuous distribution.

The expected value of an uncertainty node is the sum of all probability-weighted expected values of the outcomes stemming from that node. In this way, working back from the end, or right-hand side of the tree, expected values can be calculated for every outcome. Once all the expected values have been calculated, the optimal decision route—the one along maximum expected value—can be taken.

The same method works for more complicated decisions (next page). In this example, the decision to buy acreage or not depends on understanding the possible outcomes of a succession of decisions, including to run a seismic survey or not, to drill or not, and to drill a second well or not. The possible final outcomes—large field, marginal field and dry hole—are the same regardless of the decision route. However, they have different probabilities of occurrence at different stages of the decision tree because as the tree grows, more information becomes available. For this decision tree, the solution that delivers the highest expected monetary value traces the following branches: Buy acreage, run seismic survey, seismic survey confirms lead, drill—and if the first hole is dry, drill a second wildcat.

Assigning probabilities to the tree branches requires technical expertise and, in this case, relies on prior knowledge of the region. The likelihood and value of the various outcomes also can be based on the result of more detailed Monte Carlo simulations. For example, the cutoff value for what constitutes a large field could be the high side of a probability distribution that is the result of Monte Carlo simulation of the reservoir volume parameter.

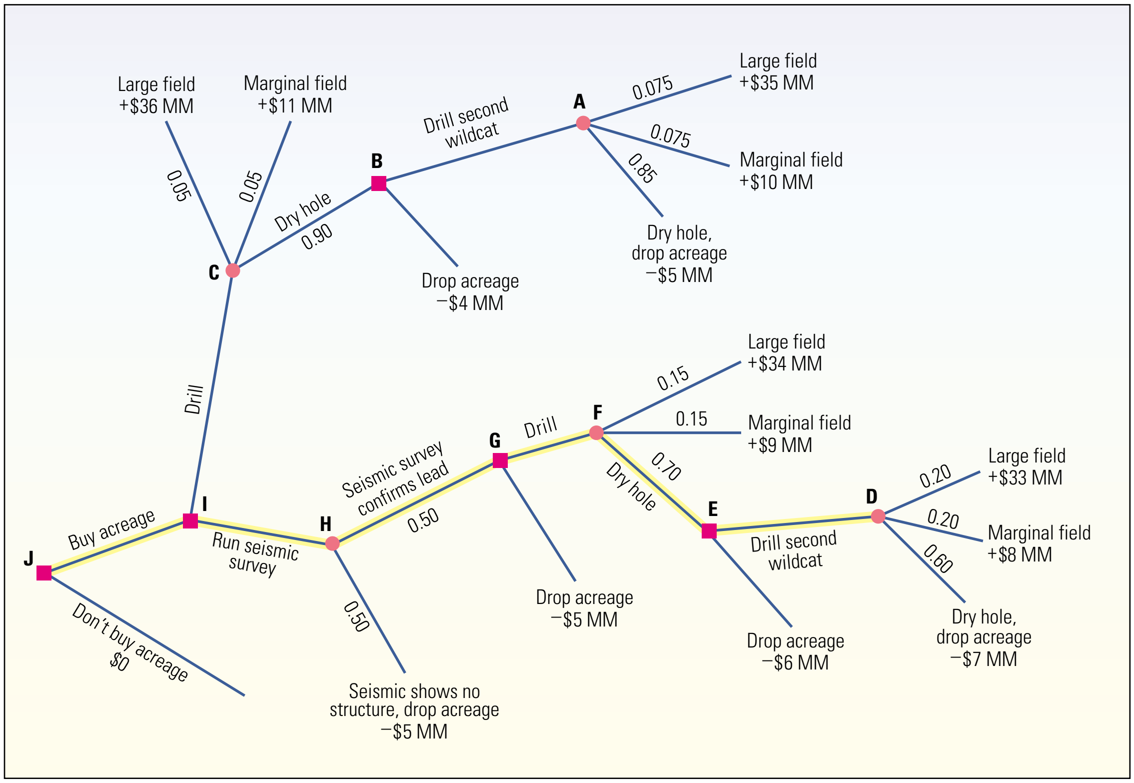
Depending on the type of decision to be made, specialists from many oilfield disciplines may be called upon to supply information for decision-tree analysis. In addition to the unknown reservoir size and content, outcomes that need to be predicted include the following:

- price of oil and gas
- quality and reliability of seismic imaging or logging data
- cost and risk versus value of additional information
- likelihood of drillpipe or logging tools getting stuck, and other nonproductive rig time
- reservoir compartmentalization, or number of wells
- reservoir fluid properties and performance
- completion complexity
- cost of transport to market
- improvement gain from stimulation, workover or enhanced-recovery methods.

Less obvious to many oilfield professionals, perhaps, but also important to estimate in cases that lend themselves to decision-tree analyses, are eventualities such as government legislation and stability, company mergers, court cases and health, safety and environment (HSE) issues.

Numerous software products are available that facilitate decision-tree analysis for oil and gas E&P and other industries. These include Precision Tree by Palisade, Decision Programming Language (DPL) by ADA (Applied Decision Analysis) and the Decision Tree package developed by Merak, a Schlumberger company. These systems link to calculation engines that compute net present values for each branch of the tree. Broadly speaking, decision-tree software packages link to Excel as the calculation engine. Only the Merak Decision Tree software also links directly to the Peep economic analysis program, which is a standard asset-management package in the petroleum industry.

Decision trees can be helpful for analyzing many types of oilfield decisions. Examples include deciding whether to replace wireline logs with logs acquired while drilling, evaluating waterflood programs, optimizing workovers, and choosing the best offshore platform topsides configuration.[5] The next section describes how decision trees can help evaluate a deepwater production system.



^ More complicated decision tree for buying acreage. In this example, the decision depends on a succession of decisions (highlighted in yellow) including running a seismic survey and drilling one or two wells. (Adapted from Newendorp, reference 1.)

Choosing a Production System

Aker Maritime, Inc., a maker of offshore platforms and spars, was approached by an operator preparing to select a deepwater production system for a development offshore West Africa.[6] The client had to decide whether to act early and buy a production system that could be adapted in case the reservoir turned out to be larger than expected, or wait for more information and optimize the size of the system. An early decision could mean quicker production of first oil. And an adaptive system has the flexibility to allow for future additions of fluid-processing modules or wells. However, such a decision would be based on minimal information. The alternative was to drill more wells, acquire more information and buy a production system optimized for the reservoir size, but at additional expense and production delay.

Aker Maritime worked with Decision Frameworks, a decision analysis and facilitation consulting firm, to structure the decision and model development alternatives. The Decision Frameworks approach relies on technical and commercial petroleum-industry expertise paired with Merak software, specifically the Decision Tree product and Peep economic database application.

The first steps in the decision analysis were to structure the problem, understand issues associated with the deepwater discovery and review alternative development solutions.

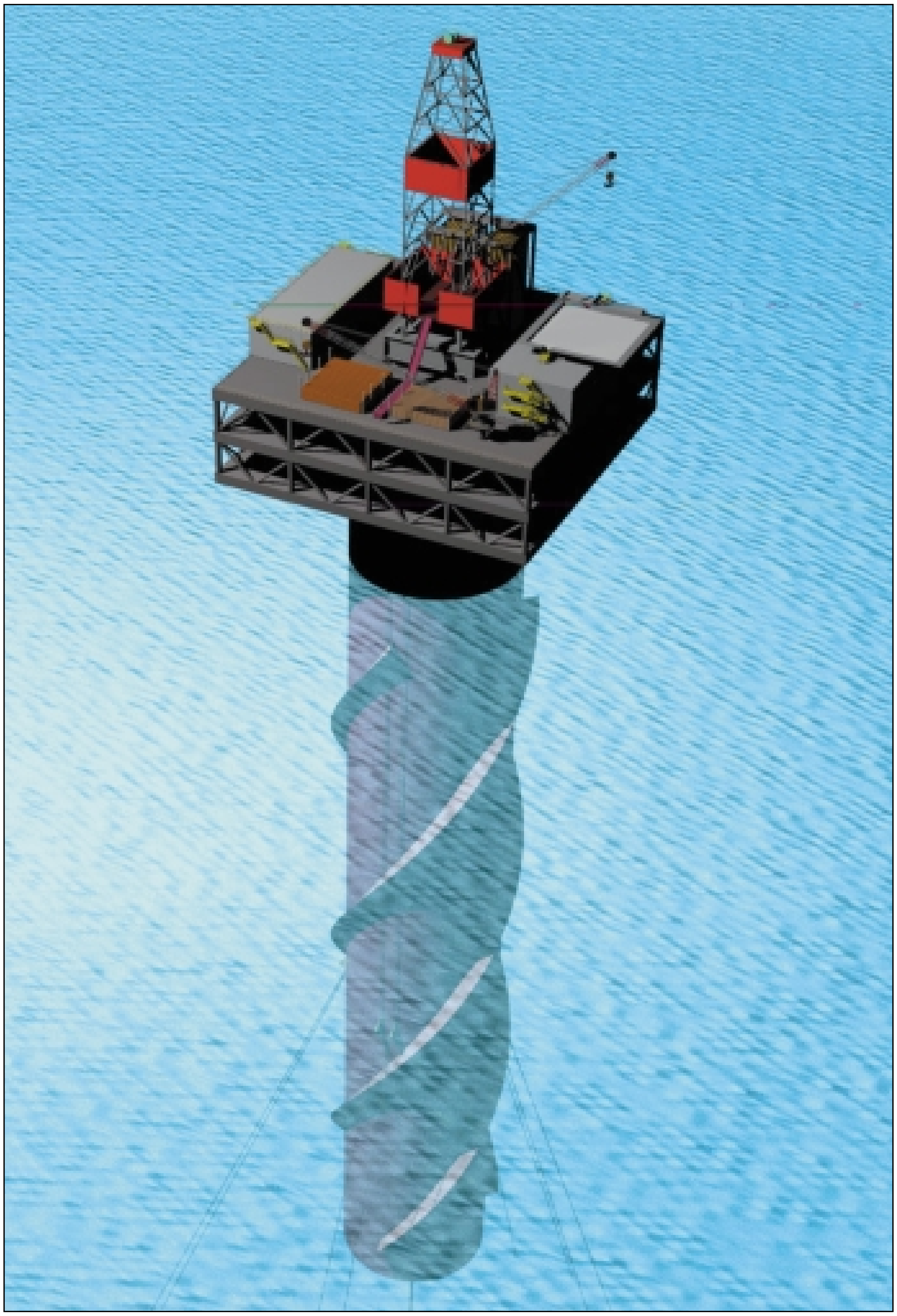
5. Beck GF: "Examination of MWD (Measuring While Drilling) Wireline Replacement by Decision Analysis Methods: Two Case Studies," *Transactions of the SPWLA 37th Annual Logging Symposium*, New Orleans, Louisiana, USA, June 16-19, 1996, paper U.

   Martinsen R, Kjelstadli RM, Ross C and Rostad H: "The Valhall Waterflood Evaluation: A Decision Analysis Case Study," paper SPE 38926, presented at the SPE Technical Conference and Exhibition, San Antonio, Texas, USA, October 5-8, 1997.

   Macary S and El-Haddad A: "Decision Trees Optimize Workover Program," *Oil & Gas Journal* 96, no. 51 (December 21, 1998): 93-97, 100.

   MacDonald JJ and Smith RS: "Decision Trees Clarify Novel Technology Applications," *Oil & Gas Journal* 95, no. 8 (February 24, 1997): 69-71, 74-76.

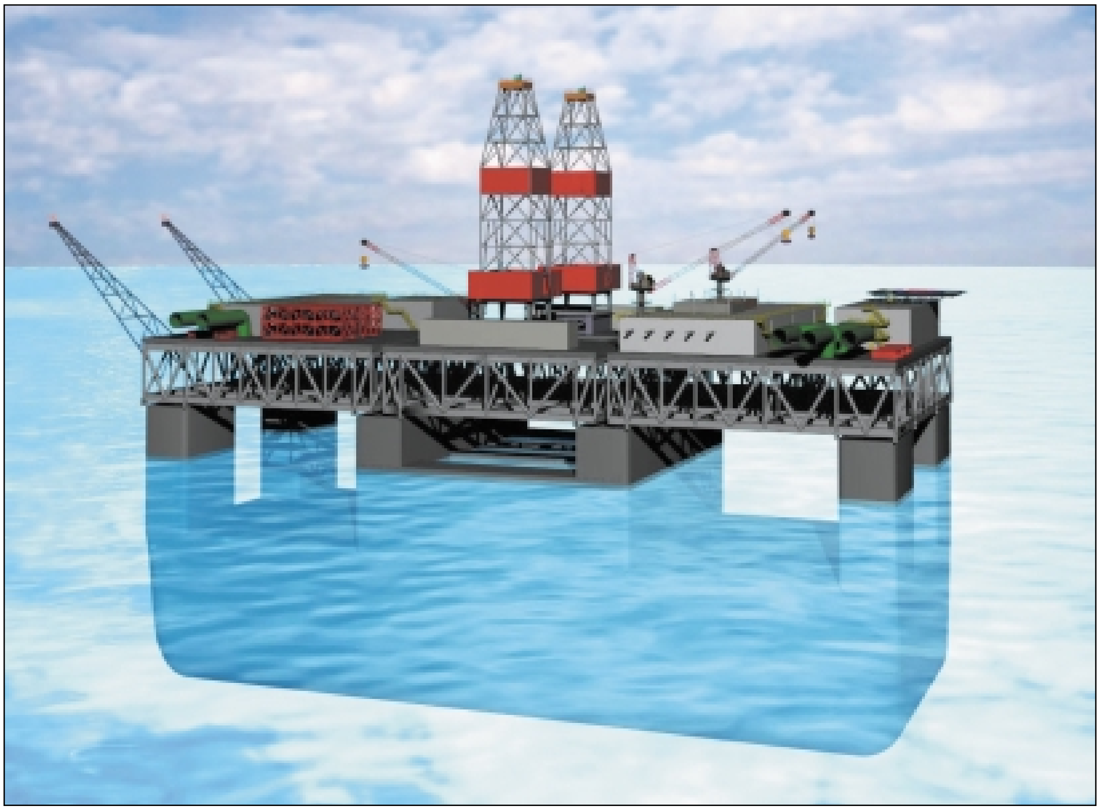
6. A spar, sometimes called a dry-tree unit, is a floating vertical cylinder that is moored to the seafloor. Spars allow production from deepwater fields to "dry" surface facilities as opposed to subsea facilities.



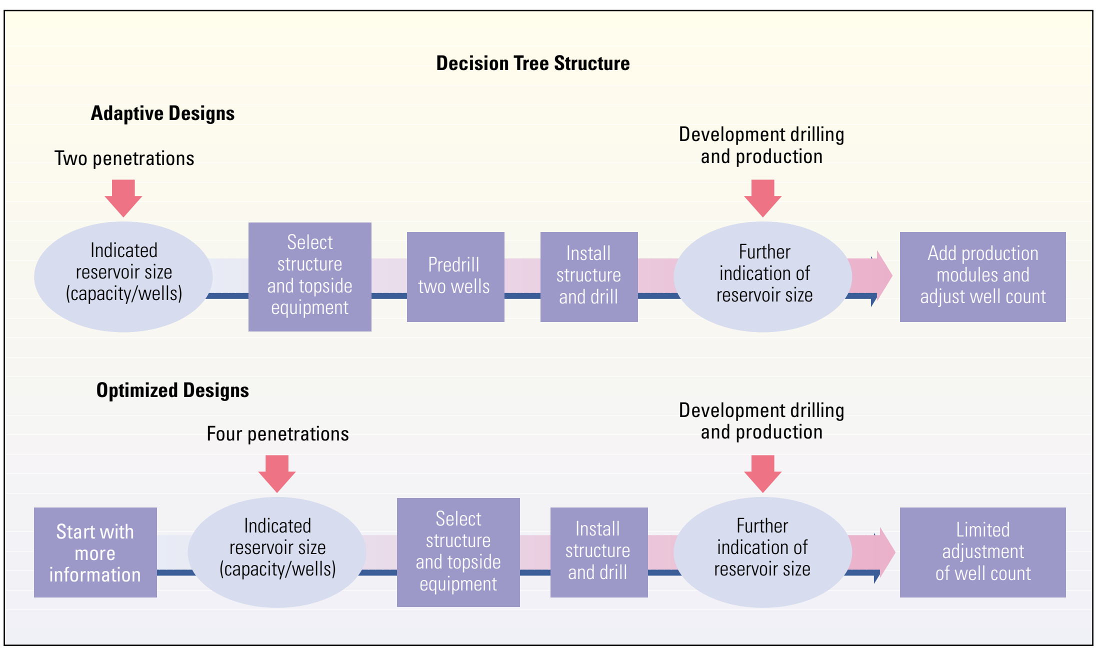
^ Aker Maritime adaptive spar.

Decision Frameworks worked with Aker and their oil company client to define parameters of the discovery, such as reservoir size, production rates, number of wells and drilling schedule. Then, high-level decision trees were constructed for the four development concepts under consideration. Two concepts were adaptive structures, the Aker adaptive spar and DPS-2000 (above and next page, top). The other two were designs that could be optimized to suit the reservoir size: a floating production, storage and offloading (FPSO) system and an optimized spar. All four concepts allowed oil storage.

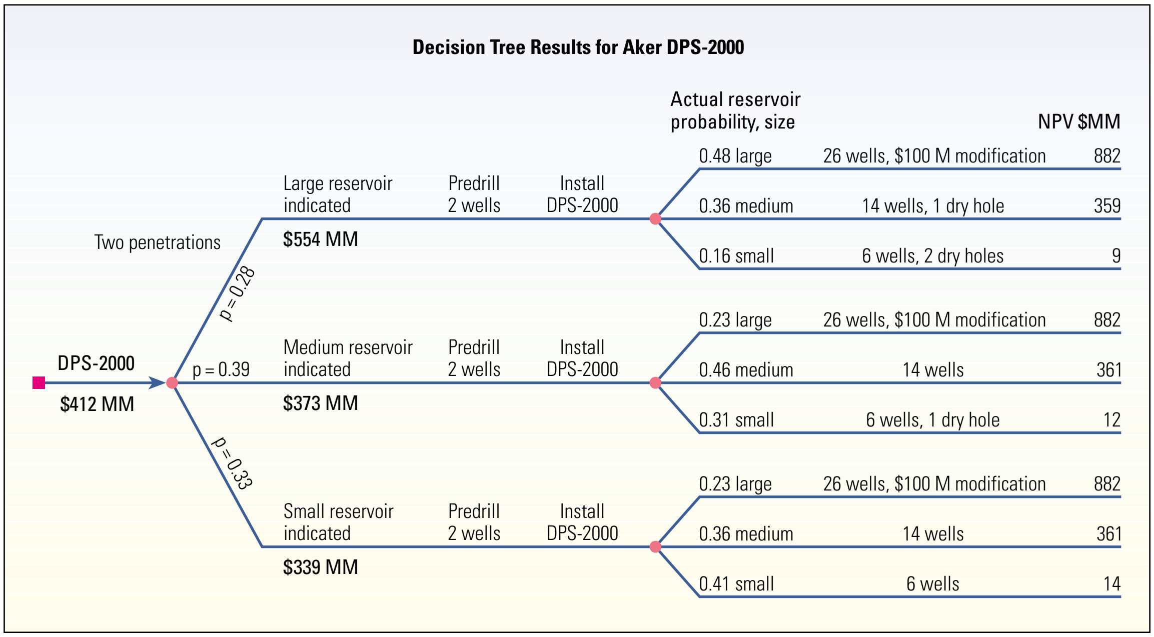
The Decision Tree analysis for the adaptive designs called for selection of surface structure and topsides based on information from only two wells. This was followed by drilling of two wells, installation of the structure, development drilling and production, then installation of additional production modules or wells as necessary (next page, bottom). The case of optimized designs starts with information from four wells before selecting and installing the production system, followed by drilling of additional development wells and finally some limited adjustment of the well count, depending on what production information indicated the size of the actual reservoir to be.



^ Aker Maritime DPS-2000.



^ Decision Tree structure for adaptive design compared to optimized design. The adaptive design *(top)* starts with less information and drills fewer wells. The optimized design *(bottom)* uses information from four wells to size the development concept.



^ Decision Tree output showing NPV calculated for the DPS-2000 adaptive deepwater system.

The key uncertainty was the reservoir size, which governs the facility capacity and the number of wells required to develop the reserves. The results of the Decision Tree analysis are the economic impacts of multiple scenarios that occur if the reservoir is:

- believed to be large and actually is large, medium or small;
- believed to be medium and actually is large, medium or small;
- believed to be small and actually is large, medium or small.

A sample decision tree demonstrates the net present values calculated for one of the four development concepts: the DPS-2000 adaptive system (above). The total NPV for this concept is $412 million. Comparing this figure to those obtained for the other three concepts shows the DPS-2000 to have the greatest NPV (below left).

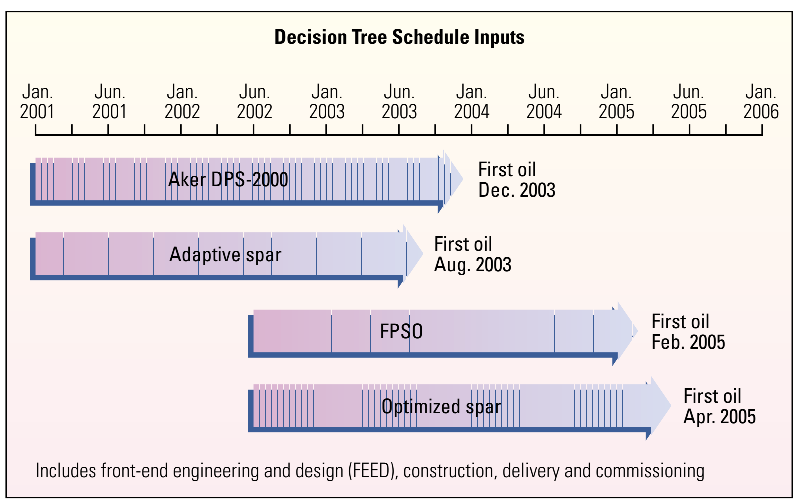
The timing of the steps in the development plays a key role in investment payback. A large part of the value in selecting an adaptive system is in the reduced time to first oil. The Decision Tree software followed a schedule from January 2001 to June 2005 that included front-end engineering and design (FEED), construction, delivery and commissioning (below right). Both adaptive concepts could deliver first oil in 2003, compared with the 2005 deliveries possible with the optimized systems. However, the added value of the adaptive systems was accompanied by added risk.

The Decision Tree software helped demonstrate the added value achievable with the early adaptive production systems and allowed Aker Maritime to present a full range of decision options to the oil company client. It also underscored the fact that uncertainty often exists even after more information is gathered. Recognizing this during the selection of development concepts is important, and can add value.

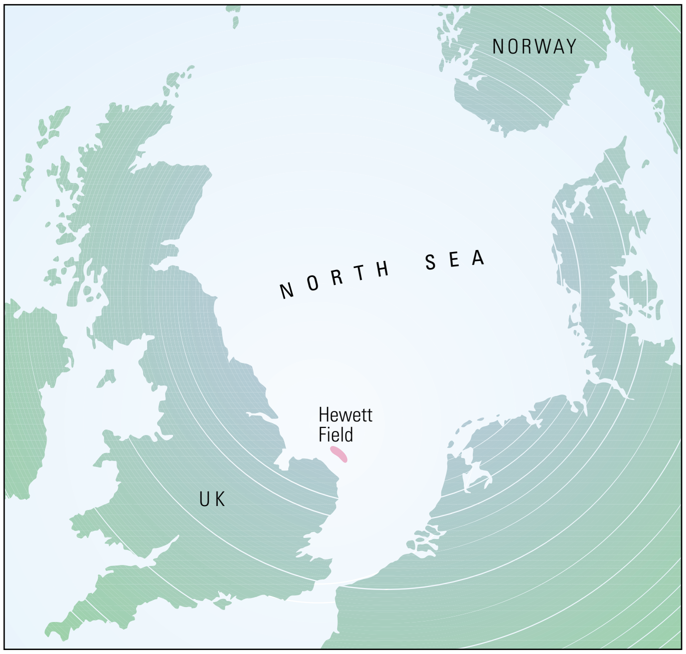
Value Captured

Adaptive Concepts		Optimized Concepts	
DPS-2000	$412 MM	Optimized spar	$313 MM
Adaptive spar	$350 MM	FPSO	$182 MM

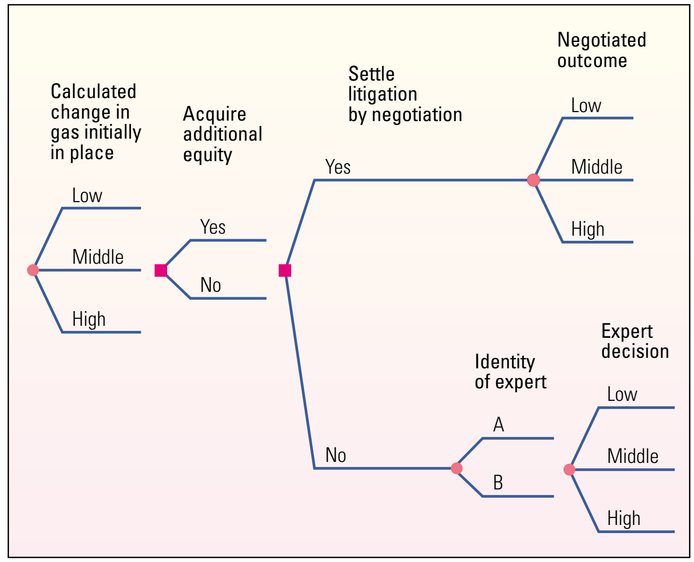
^ Comparison of final NPV calculations for the four development concepts under consideration. The adaptive concepts offer up to $230 million higher NPV than the optimized concepts.



^ Schedule of Decision Tree events. The adaptive concepts start first and produce first, while production from the optimized projects lags by about 18 months.



^ Hewett field, UK North Sea, where low yields prevented Centrica and partners from meeting contracts to provide gas. Decision Tree analysis helped Centrica decide whether to proceed with the ensuing settlement.



^ Schematic decision tree created to help Centrica analysts reach a decision on the Hewett field case. The tree uses a compact notation whereby a node next to the outcomes of a previous node means that node is repeated for each input branch. In this way, the first decision node, "Acquire additional equity," applies to all three outcomes of the previous node, "Calculated change in gas initially in place." Similarly, the decision node to settle by negotiation applies to all Yes or No outcomes of the previous decision, and so on. This notation conveys the same information as a whole tree but keeps the tree compact and manageable.

Making a Case

The decision-tree methodology also can be applied to other types of E&P problems. As part of Centrica's strategy to acquire additional UK continental shelf assets, the company can—when it already has contracts to buy the gas from the assets—often be required to consider potentially conflicting buyer-seller interests. In one example, Centrica needed to consider the impact of a past dispute on the future value of an asset under consideration. The dispute related to the previous failure of the sellers to meet contractual obligations to provide gas and to Centrica's application of the contractual remedies. The sellers objected to this action and litigated to limit it. Centrica had to consider the possible outcomes from a litigated versus negotiated settlement on the future value of the asset—the Hewett field (above).

Several conditions complicated the decision process. Acquiring additional equity in the field or taking on operatorship could increase reserves and value, and allow Centrica to provide more gas, but the field was old and nearing expensive abandonment. However, there also was potential for workover or developing neighboring fields. So many elements were involved in the decision that the problem appeared quite difficult to solve.

Centrica consulted with AEA Technology plc to help them frame the problem. The resulting decision tree was large, requiring evaluation of 7000 alternatives with hours of computer runs per outcome that totalled a man-year of effort. An automated solution was needed to generate and input numbers for the decision tree. Centrica analysts used the Merak Decision Tree product, and, by paring down some of the constraints, were able to achieve a solution with 500 outcomes and computer run times of 7 minutes (above right).

The benefits of a Decision Tree solution were twofold: first, the decision-analysis process provided clear insight into the problem. In spite of the complexity of the situation, the Decision Tree results clarified what was driving the decision as well as the direction to be taken. For the first time, everyone involved was in agreement with the rationale for the set of decisions. Second, the Merak tools made it easy to solve the problem and completed the calculations and analysis quickly.

Simplifying Decision-Making

For large organizations like those in the petroleum industry, it is still people, not processes, that make complex, expensive decisions. The decision-analysis technique is usually customized from one organization to the next, but the most successful system is one of framing the problem, understanding uncertainties, developing stronger, often hybrid solutions, and balancing risk against expected value.

As the petroleum E&P industry continues to pursue prospects in more remote and potentially sensitive regions, decision-making tools that incorporate information from all sources of expertise will make important contributions to project success.

Although decisions are ultimately made by people, computer and software solutions make the job easier. Decision-analysis products can help identify how sensitive a decision is to all the factors involved, determine the value of moving ahead or gathering data, point decision-makers in the most valuable direction, and produce more consistent decisions.

The benefits of a consistent decision-analysis process are felt by decision-makers in all parts of the company, allowing technical staff and planning organizations to increase the efficiency and value of their work. —LS