INTEGRATING BUSINESS STRATEGY AND CAPITAL ALLOCATION: AN APPLICATION OF MULTI-OBJECTIVE DECISION MAKING

MICHAEL R. WALLS
Colorado School of Mines

ABSTRACT

A fundamental element of the business strategy process is allocating capital and corporate resources. Managers of this process are often faced with complicating factors such as financial risk and uncertainty about potential outcomes. This paper describes a decision science methodology for systematically integrating the processes of business strategy and capital allocation. We present an application of this methodology by a large oil and gas company concerned with allocating an annual $200 million capital budget. This approach is shown to have broad implications for managers in all sectors and provides rich insight into the effects of integrating corporate objectives and risk policy into the investment choice process.

INTRODUCTION

The emphasis placed on strategic planning in firms over the last two decades reflects the proposition that there are significant benefits to gain through an explicit process of formulating strategy toward some common set of goals or objectives. Companies in all business sectors are periodically faced with the very basic business strategy questions of "How should we compete in our business and what are our important objectives?" Perhaps the most fundamental issue associated with effecting a firm's business strategy is the process of allocating scarce investment capital, in the face of business risks and uncertainties. To structure and quantify this class of strategic decision, this paper describes a multi-objective decision model designed to aid decision makers in the allocation of capital across a set of risky investment opportunities. The model application presented demonstrates that once a set of corporate objectives are specified, utility functions can be constructed that consider management's value tradeoffs among business objectives and propensity to participate in risky projects. This multi-attribute utility theory (MAUT) approach was utilized to identify the appropriate mix of investments for a large oil company, consistent with its corporate objectives and overall business strategy. Results of this model application guided senior planners into a formal evaluation of capital investment projects and provided significant insight into major resource allocation decisions.

This work intends to provide an important link between (1) the strategic management process, which is concerned with how a business is going to compete, what its objectives should be and what set of decisions is needed to achieve those objectives; and (2) the multi-objective decision making techniques from the field of decision analysis. The formal and systematic approach associated with MAUT provides a naturally appropriate decision model for the strategic management process. The process of setting corporate objectives, defining business decision alternatives, establishing management values, and modeling the uncertainty associated with the business environment all represent critical components of both the MAUT approach to decision making and the sum and substance of business strategy. The application of the model is to the oil and gas industry sector; however, the MAUT approach to business strategy and capital allocation is applicable to any business sector.

In the first section of the paper a brief background of previous applications of multi-attribute utility theory are presented. The next section describes the general problem faced by managers in terms of allocating scarce investment capital and its relationship to business strategy. This section discusses how traditional capital budgeting theory is an inadequate model for incorporating the strategic issues managers are concerned with into the capital allocation process. The next section presents the foundations of decision analysis and multi-attribute utility theory. This section shows how these models provide managers a systematic and comprehensive approach to decision making under conditions of risk and uncertainty. The paper then describes the basic capital allocation/strategy dilemma faced by a large oil and gas exploration company. A step-by-step application of the MAUT model is presented which includes setting strategic objectives, determining the decision maker's value tradeoffs and risk attitudes and evaluating capital allocation alternatives. This section describes how the firm used the MAUT model to choose the appropriate portfolio consistent with its business objectives. The paper is concluded with a discussion of the portfolio model and its implications with regard to affecting a coherent risk policy, improving the quality of decisions and providing a framework for effecting a competitive business strategy.

APPLICATIONS OF MAUT

Multi-attribute utility theory (MAUT) normally presumes a single decision maker who is to choose among a number of alternatives that he or she evaluates on the basis of two or more criteria or attributes. The alternatives involve risks and uncertainties and may require sequential actions at different times. The decision maker acts to maximize a utility function that depends on the criteria or attributes. MAUT embraces both a large body of mathematical theory for utility models and a wide range of practical assessment techniques that together assist in the decision problem to rank alternatives, make a choice, or otherwise clarify a situation for the decision maker. Sensitivity analysis is often involved in the assessment and choice processes.

Applications of MAUT in the public sector far outnumber applications of this type of decision model in the private sector. Because most public sector problems involve multiple conflicting objectives, such as in public health care systems (Lathrop & Watson [22]), environmental policy (Ulvila & Snyder [29]) regulatory issues (Von Winterfeldt [31]; Keeney & Smith [20]), site selection (Kirkwood [21], de Neufville & Keeney [8]; Sarin [26]), energy (Beley [2]) or public policy (Anandalingam [1]; Bodily [4]), the opportunities for MAUT applications have been apparent and numerous. Considerably fewer applications of MAUT to corporate problems are found in the decision analysis and operations research literature. Keefer & Kirkwood [15] discuss an application to optimally allocate an operating budget for project engineering. Keeney [16] discusses the assessment of a multiple objective corporate utility function to examine corporate policies. Dyer & Lund [9] analyze new strategies for merchandising gasoline and Hax & Willig [12] apply MAUT to the capital investment problem in a mining firm. Though other applications of MAUT in the private sector have been undertaken, there exists a continuing need for good documented applications. One such need is the contribution that MAUT models can provide to the private sector in terms of developing an effective link between the firm's capital allocation process and its business strategy.

THE PROBLEM

Managers regularly face the problem of constructing the appropriate portfolio of investment opportunities consistent with the firm's business objectives. Decisions about capital allocations may focus on selecting the appropriate mix of high risk versus low risk projects, domestic versus foreign activity, R&D versus production, acquisition versus expansion, as well as a host of other complicating dimensions. Because of these issues and the significant amounts of capital at stake, the firm's capital budgeting process represents a fundamentally important task in terms of the firm's overall competitive strategy and performance.

Traditional capital budgeting theory focuses on the concept of building or maximizing shareholder value. The strategy issues described above differ from the assumptions underlying traditional capital budgeting theory in several respects. First, the theory assumes that choice among project alternatives is the key step in the capital budgeting process. In fact, the theoretical characterization of a project as a financial security, and the focus on a discrete and identifiable set of choices made by top management, make for a descriptively inaccurate conceptual framework. Second, the theory is correct in the special case where a zero level of uncertainty exists. Traditional capital budgeting theory requires a certain and accurate projection of cash flows for independent and mutually exclusive projects. Often times decisions concerning resource allocation are characterized by a high degree of uncertainty along any number of dimensions.

Third, traditional capital budgeting theory assumes the organization is concerned with maximizing a single objective, net present value. The modern business enterprise, however, is concerned with a complex set of corporate and business objectives. The strategic management literature refers to this as the "stakeholder theory" of objectives. This theory maintains that the objectives of the firm are derived by balancing the conflicting claims of the various stakeholders in the firm: managers, workers, stockholders, suppliers, vendors, and even local communities. Hackett [11] noted that it is unrealistic to assume that managers are merely agents for shareholders. The firm has a responsibility to all stakeholders and must configure its objectives to provide each a measure of satisfaction. Maximization of net present value is one of such satisfactions, but does not necessarily receive special predominance in the objectives structure.

Complexity in the resource allocation process cannot be avoided in making decisions. There are, however, options concerning the degree of formality used to address the complexity. Top management is capable of coping with this complexity by determining how the company will compete in its business, articulating that strategy by specifying a set of corporate objectives, and utilizing a decision model designed to achieve those objectives. Any reasonable decision model must obtain and combine available information, explore and evaluate critical value tradeoffs, recognize the uncertainty for each alternative and incorporate the business objectives of the firm. A comprehensive model must also appraise the degree to which each objective is achieved by the competing alternatives. MAUT models provide a framework for dealing with complex problems and systematically analyzing available alternatives.

DECISION ANALYSIS AND MULTI-ATTRIBUTE UTILITY THEORY

Making important decisions often requires incorporating major uncertainties, risk, long time horizons, multiple alternatives, and complex value issues into the decision model. To deal with such problems, the discipline of decision analysis was developed. Decision analysis is defined by Howard [13] as "*a discipline comprising the philosophy, theory, methodology, and professional practice necessary to formalize the analysis of important decisions.*" Keeney [18] provides a more intuitive definition as "a formalization of common sense for decision problems which are too complex for informal use of common sense."

The foundations of decision analysis are provided by a set of axioms stated alternatively in von Neumann and Morgenstern [30], Savage [27], and Pratt, Raiffa, and Schlaifer [24]. These axioms, which provide principles for analyzing decision problems, imply that the attractiveness of alternatives should depend on (1) the likelihood of the possible consequences of each alternative, and (2) the preferences of the decision makers for those consequences. The ultimate purpose of decision analysis is to help decision makers make better decisions. The analysis provides a basis for the decision, not just the decision itself. Information gaps can be uncovered and filled, differences in values can be openly examined and communication about objectives, values and risk attitudes become more open within the organizational structure.

Single and multi-objective decision analysis provide the firm strategic choice models -- models which provide a systematic and comprehensive approach to decision making. A formal description of the decision problem in decision analysis is characterized as the "*comprehensive decision basis*" after Howard [13]. (See Figure 1.) The comprehensive decision basis consists of a quantitative specification of the four fundamental elements of the decision problem: the strategy, the choice, the information and the preferences of the decision maker or firm. Each of these components may have varying degrees of complexity. Structuring the decision problem requires the firm to specify a strategy as defined by a set of objectives as well as individual attributes to measure the achievement of those objectives. The choice element consists of identifying the proposed or available decision alternatives. In the information phase the analyst assesses the impact of each alternative on the set of objectives. This phase may involve long time horizons, probabilistic information about outcomes and probabilistic dependencies among attributes for different alternatives. The preference assessment phase focuses on formally measuring the decision maker's value tradeoffs among objectives, equity concerns and risk attitudes. Value tradeoffs and risk attitudes are particularly complicated because there are no right or wrong values. Basically, what is needed is an objective function which aggregates the firm's objectives and attitudes toward risk. In decision analysis, such an objective function is referred to as a utility function.

A MODEL APPLICATION

The MAUT model described below was utilized by a large independent oil company based in Houston, Texas, which is active in petroleum exploration both in the United States and abroad. As an indicator of the relative importance of exploration resource allocation, the company's annual exploration budget was approximately $200 million, about 75% of the firm's overall capital budget. Total asset value of the firm was approximately $2 billion. As is the case for most large independent and integrated oil companies, exploration activities were

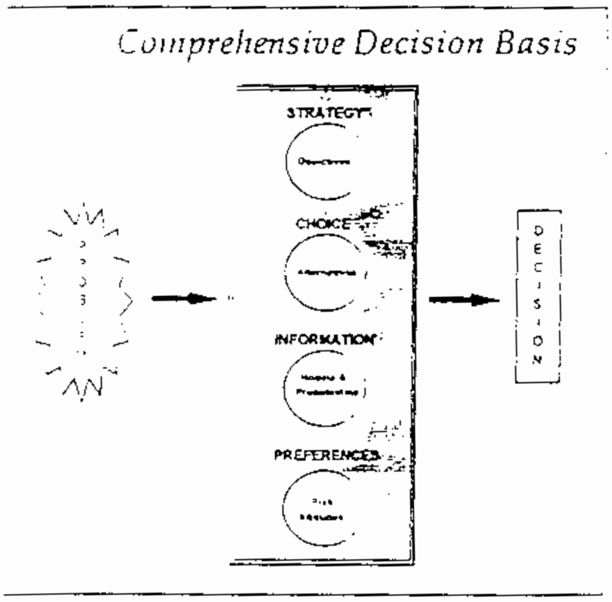

FIGURE 1. Each of the elements of the comprehensive decision basis are elicited from the decision maker or his delegates; the decision basis should accurately represent the strategy, alternatives, information and preferences provided directly or indirectly by the decision maker.

located in a broad range of geologic settings with varying degrees of oil and gas reserve potential. Chance of success as well as the distribution of possible reserve outcomes varied significantly within these various exploration regions. Other sources of uncertainty such as price risk and political risk also existed. Management was concerned with evaluating these diverse projects consistently with respect to each component of risk and uncertainty as well as constructing an exploration portfolio consistent with the firm's business objectives. It is also important to note that the company had available more positive expected net present value projects than available investment capital. Therefore, it was important to determine the appropriate level of diversification among the set of exploration projects available to the firm. An important part of this process was to identify the optimal level of participation in each project.

SETTING STRATEGIC OBJECTIVES

Objectives are widely recognized as essential for informed decision making. All organizations and individuals have objectives and values, either explicit or implicit, that guide their decisions to some extent. (Keeney & McDaniels, [19]). Authorities on strategic management often discuss the need for objectives, sometimes cast in terms of mission statements or organizational goals, as a key step in developing approaches to strategic management. Clarity of organizational values and the integration of multiple objectives has become increasingly important as firms deal with more complex decision tasks (Byars [5] & Thompson [28]).

Unless an organization's mission and direction are translated into measurable performance targets an organization's mission statement is just window dressing. Companies whose managers set objectives for each key result area and then aggressively pursue actions calculated to achieve their performance targets are strong candidates to outperform companies whose managers operate with hopes, prayers and good intentions. Explicitly stating organizational objectives in measurable terms and then holding managers accountable for reaching their assigned targets substitutes purposeful strategic decision-making for aimless actions and confusion over what to accomplish and provides a set of benchmarks for judging the organization's performance.

The first step in the MAUT analysis was for the company to articulate a business strategy with regard to its exploration efforts. This part of the model development focused on identifying those performance objectives that management judged to be important to the overall success of the firm. For this purpose, the analyst met with key personnel to obtain their view on those objectives important to the company. This open discussion was designed to result in a well-articulated set of objectives which were fundamental to the firm's overall strategic objective. The "objective hierarchy" provides a structure for clarifying the values of interest and a visual representation of the company's business objectives for a given context. In the case of this oil company, management agreed that the firm's overall strategic objective was to "improve business unit's overall performance". Management rendered this very general overall objective more useful by specifying a set of measurable sub-objectives.

For example, the company specified as the major sub-objective "select the best E&P project portfolio". Guided by the analyst, management identified what factors were fundamentally important in the context of achieving this objective ensuring that important sub-objectives were not omitted. Figure 2 depicts a hierarchy of the overall objective with a set of sub-objectives that were used to evaluate decision alternatives.

These sub-objectives were consistent with the company's fundamental business strategy as well as its publicly stated corporate objectives. It is important to specify an attribute to measure the degree to which each of these sub-objectives is achieved. For example, the attribute associated with "maximize reserve replacement" is the reserve replacement percentage which was defined as reserves booked for the budget period divided by the amount of reserves produced for that same period times 100. The objectives and their corresponding attributes of measurement were as follows:

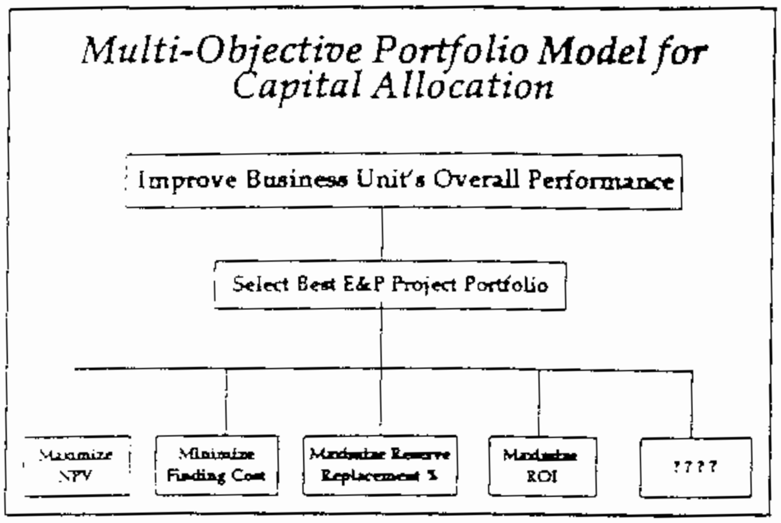

FIGURE 2. Hierarchy shows overall strategic objective and the set of sub-objectives by which exploration portfolio alternatives were judged. The box with question marks indicates that any number of additional sub-objectives could have been incorporated into the decision model.

- Maximize the reserve replacement percentage (booked BOE[1]/produced BOE x 100)
- Minimize portfolio reserve finding costs ($ expenditure/BOE reserves)
- Maximize portfolio net present value ($ net present value)
- Maximize the portfolio return on investment (a profitability index measured as discounted profit/total investment)

The second step in this process was to develop a *scenario generation model* which would enable management to observe the effects of portfolio changes on each business objective. Beginning with the firm's current portfolio of projects, this spreadsheet-based model computed the expected performance measures on each dimension of interest. Based on the outcome distributions for each of the unknowns associated with each exploration project, which were provided by the company's geologists and engineers, the scenario generation model utilized monte carlo simulation to compute a probability distribution for each attribute of the project portfolio. For example, in the current exploration portfolio, the model computed a probability distribution on reserve replacement percentage, finding costs, net present value and the profitability index (ROI). These initial valuations were based on the firm's current portfolio of exploration projects and the levels of participation associated with each of those projects.

To investigate the effects on the company's business objectives, the mix of projects in the portfolio were changed. Management provided minimum and maximum participation levels for each of the projects available to the firm. These values represented a range of the possible participation levels available to the firm for each project. For example, though the firm may hold or have available a current interest of 50% in a given project, it may also have the option to participate at up to a 100% level or to completely reject the project (minimum interest of 0%). If the firm had an opportunity to take multiple projects in a particular exploration context, the firm could specify an upper bound on the number of projects available in this category.

Simulation was utilized to generate over 2500 potential portfolios based on changes in participation levels for each project. For each portfolio, a distribution of possible outcomes was computed for each of the objectives specified by management. Expected values were also computed for each performance dimension, enabling management to readily compare each revised portfolio to the company's current mix of projects. Since these preliminary comparisons were on an expected value basis, they were independent of management's risk preferences about each dimension. Operating constraints, such as contractual drilling commitments, working interest participation agreements and total exploration budget constraints (both maximum and minimum) were an integral part of the model. Simulated portfolios which did not meet these management-specified constraints were deleted from the analysis.

Upon completion of the scenario generation model, the data were reviewed with management in order to clarify the set of outcomes generated and to identify the range of possible outcomes for each of the attributes (NPV, finding cost, etc.). The range of possible outcomes for each of the performance objectives from a simulation on the company's exploration opportunities is shown in Table 1. These performance values represented the best and worst portfolio outcomes evaluated in the simulation. These values do not represent expected outcomes, but rather, the best and worst possible outcomes on each dimension over the set of 2500 portfolios generated. Ranges established are an important component in the assessment of utility functions and value tradeoffs. These ranges are essential so that priorities among objectives can be set in a way that makes sense and has a meaningful interpretation to management.

ASSESSING THE COMPANY'S UTILITY FUNCTION AND TRADEOFFS OF OBJECTIVES

In this strategy/capital allocation problem it would likely be impossible to achieve the best level with respect to each objective. That naturally leads us to the question of" How much should be given up with regard to one objective to achieve a specified level on another?" This problem relates to the fundamental issue of value tradeoffs. As shown in the case of the objective hierarchy in Figure 2, business objectives are often conflicting in nature. For example,

TABLE 1. A list of objectives, attributes and ranges based on the portfolio scenario generation model. Attributes are in parentheses. Worst and best refer to levels of the attribute.

Objectives/Attributes of Interest	Worst Level	Best Level
Reserve Replacement Percent (booked BOE/produced BOE x 100), x_1	30%	670%
Finding Cost ($ expenditure/BOE reserves), x_2	$9.25/BOE	$2.10/BOE
Net Present Value ($ NPV), x_3	$-60 Million	$930 Million
Return on Investment (Disc. Net Profit/Investment), x_4	0.60	22.0

maximizing reserve replacement for the current period was not necessarily consistent with maximizing net present value. Large, capital intensive projects characterized by high net present values would require long periods for development. As a consequence, short term reserve replacement may be quite low. It was necessary for management to define those tradeoffs and integrate them into a allocation model that would be consistent with the firm's overall business strategy.

Risk and uncertainty were also important issues in the context of achieving corporate objectives. There were risks and uncertainties associated with each of the attributes in the exploration portfolio selection problem. For this reason, some measure of the firm's willingness to accept these risks was necessary for development of an effective decision model. Basically, what was needed was an objective function which aggregated all the individual objectives and an attitude toward risk; to achieve this a utility function, symbolically written $u(x)$, was constructed. Then $u(x)$, the utility of the consequence x, would indicate the desirability of x relative to all other consequences over the range of interest. Since the company's preferences about uncertain outcomes for each attribute differed, separate utility functions on each attribute were constructed. Figure 3 demonstrates that measurement of each objective's achievement is affected by the decision maker's preferences for outcomes on that objective[2].

Recall that the overall utility function had four major components defined as (1) reserve replacement percent, (2) finding costs, (3) net present value, and (4) return on investment. Utilizing the general form of the additive utility function we can specify:

$$u(x) = \sum_{i=1}^{n} k_i u_i(x_i) \qquad (1)$$

where,

i = attribute of interest

x = evaluation unit for attribute i

u = decision maker's preference for x

k = relative importance of attribute i, where $\sum_{i=1}^{n} k_i = 1$

The higher the multi-attribute utility measure, $u(x)$, the more desirable the alternative. Thus the magnitudes of the utilities for each alternative can be used to establish a ranking that indicates the decision maker's preferences for the alternatives. The utility values associated with an alternative are directly related to the objectives originally chosen to guide the decision and reflect the degree of achievement of those objectives. The decision model captures the uncertainty associated with the possible outcomes, the decision maker's preferences about those uncertain outcomes and the relative importance (k values) of the objectives developed in the hierarchy[3]. To illustrate the types of judgments necessary to determine a utility function, we provide some examples of the value trade-off and risk attitude assessment procedure utilized in this application. This procedure should be carried out with individuals holding primary decision responsibility in the firm. In the case of this oil company, primary responsibility for the exploration capital allocation decisions was held by a senior vice president (VP).

To quantify a utility function for each attribute, the VP was asked to express preference, or lack of preference (indifference) if it exists, between pairs of specified gambles or between a gamble and a certain outcome. Hence his judgments, and the resultant utility functions based on these judgments, take into account both strength of preference for various outcome states and preference or aversion for varying degrees of uncertainty. The only strict requirement on the range of payoff values encompassed by the preference curve is that the minimum and maximum values for the problem at hand are included. For example, in the assessment of the utility function on the attribute reserve replacement percentage (x_1), we are interested in focusing on the range of possible values generated in the portfolio scenario generation model, 30 to 670 percent as shown in Table 1. This is the range that corresponds to the problem at hand, the range that is important to the decision maker and the one he is most likely to be able to relate to in a consistent manner.

The utility function is mapped over the range of interest (worst and best levels from Table 1) and normalized from 0 to 1.0 by the use of scaling constants. The worst case and best case scenarios for the attribute of interest are, by definition, set at preference values of 0 and 1.0, respectively. As an example of the preference assessment procedure for reserve replacement ratio, we identify both a lottery and a consequence which are equally preferred by the decision

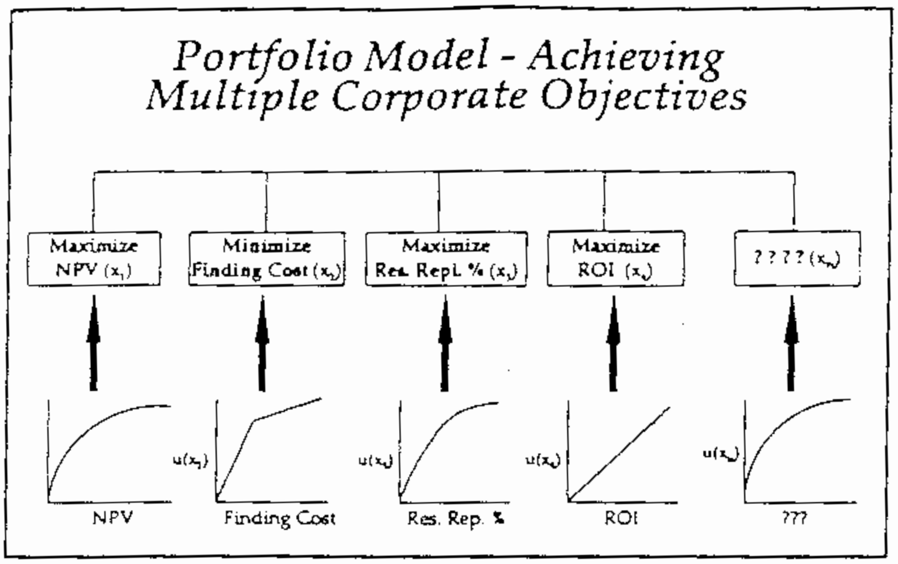

FIGURE 3. Decision maker preferences about each of the model's objectives are mapped in the form of utility functions. The utility function assessment procedure also involves evaluating the relative importance of each objective.

maker. For instance, the VP indicated he was indifferent between the certain consequence of a portfolio reserve replacement percent (RRP) of 150% and a lottery yielding either a 30% or 670% RRP with equal chances of 0.5 (see bold-face in Table 2). Then, to be consistent with the axioms of decision analysis, the utility (preference value) of an RRP value of 150% must be equal to the expected utility of the lottery. Since we have assumed that the maximum value in the range, 670%, is equal to a utility of 1.0 and the minimum value in the range, 30%, is equal to 0, then the expected utility of an RRP of 150% is equal to:

$$\begin{aligned} u\,(150\%) &= 0.5u(670\%) + 0.5u(30\%) \\ &= 0.5(1.0) + 0.5(0.0) = 0.50 \end{aligned} \tag{2}$$

The certain value (150%) which just makes the VP indifferent between the uncertain gamble and the certain value is known as the *certainty equivalent*. From this point on, the gambles depend on the certainty equivalent specified (CEQ) at each step. Table 2 shows an example of the set of gambles utilized in this procedure and the CEQ's specified by the VP for RRP. Utilizing these preference values, we were able to construct the decision maker's utility function on the attribute reserve replacement percentage (see Figure 4). This same procedure of preference assessment was utilized for each of the attributes of interest in the multi-objective decision model. The component utility functions for each attribute are then combined into the overall multi-objective utility function utilized in the portfolio model.

TABLE 2. Results of preference assessment using 50-50 gambles for the reserve replacement percentage attribute. Certainty equivalents (CEQ) represent that certain value the decision maker (VP) was just willing to take in lieu of participating in the 50-50 gamble with payoffs of outcome #1 and #2.

50-50 Gamble Assessment Procedure Attribute: Reserve Replacement Percent			
Outcome #1	**Outcome #2**	**CEQ**	**Utility**
(By Definition)		670	1.0
(By Definition)		30	0.0
670	**30**	**150**	**0.50**
670	150	300	0.75
150	30	70	0.25
70	30	45	0.125
670	300	420	0.875

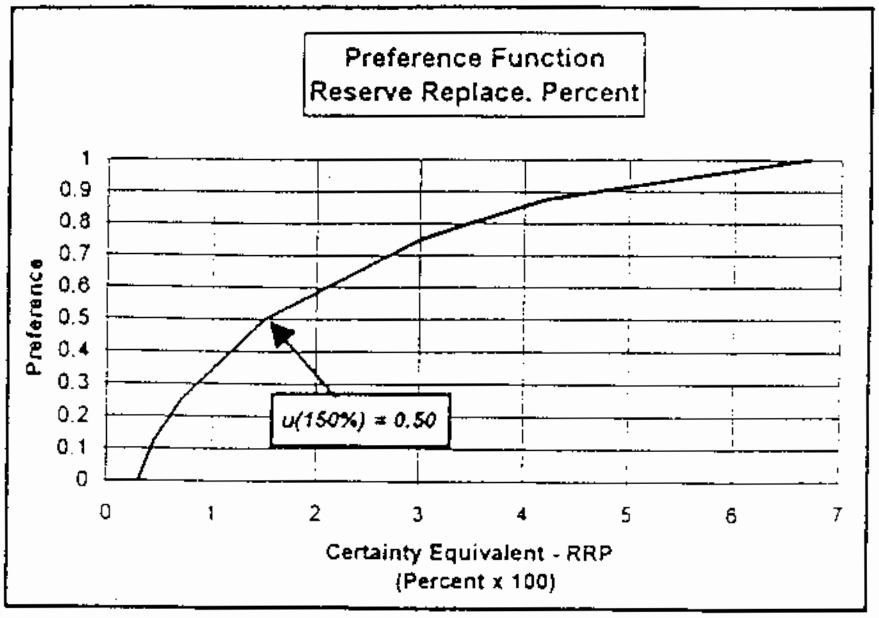

FIGURE 4. Preference function represents decision maker's utility or strength of preference for the attribute, reserve replacement ratio.

Returning to the scaling constants, k_i, in the multi-attribute utility function (Eq. 1), recall that these constants measure the decision maker's relative trade-offs among objectives. It was possible to ask the VP some meaningful questions about k_i's to get some feeling for their values. For example, the analyst asked the VP to imagine that all attributes are at their worst case; then, if he could choose only one attribute to move to its best case, which attribute would that be? The VP selected reserve replacement percentage (x_1). The second question asked of the decision maker was to choose between (1) pushing reserve replacement percentage to its best case scenario (670%) or (2) pushing all three other attributes to their best case scenario. A choice of alternative (1) implies that $k_1 > k_2 + k_3 + k_4$ and that $k_1 > 0.50$. Since alternative (1) was the VP's choice, the same procedure was used to investigate the relative importance of the remaining three attributes. Let's assume, though, that the decision maker had chosen alternative (2); this would imply that $k_1 < k_2 + k_3 + k_4$ and that $k_1 < 0.50$. In this case the analyst would ask the following question: would you rather have reserve replacement percentage (x_1) pushed to its best case scenario than net present value (x_3) and return on investment (x_4) jointly pushed to their best case scenarios? An affirmative answer implies that $k_1 > k_2 + k_3$; a negative answer implies the inverse. This type of procedure was continued until properties of the k_i's, which are reasonable approximations of the decision maker's tradeoffs among objectives, were inferred.

There are invariably inconsistencies in the initial assessments. However, the assessment procedure lends itself well to revisions, in order to more realistically represent the decision maker's values and preferences. The analyst employed systematic and formalized methods for ensuring consistency of preferences and objective tradeoffs in the assessment procedure[4]. These methods were utilized until both analyst and decision maker were comfortable with the assessment results. The following scaling constants, k_i, were assessed for each of the four major objectives:

$k_1 = 0.30$ (reserve replacement percentage)

$k_2 = 0.15$ (finding costs)

$k_3 = 0.40$ (net present value)

$k_4 = 0.15$ (return on investment)

These scaling constants must be interpreted using the ranges for each attribute in Table 1. Each scaling constant indicates the relative importance, in terms of overall contribution to the major objective of "selecting the best portfolio", of moving the corresponding attributes from their worst to their best levels in Table 1. The scaling constants allow determination of the decision maker's priorities or relative weights for the corresponding objectives.

EVALUATING AND COMPARING EXPLORATION PORTFOLIOS

Once the decision problem was structured, the magnitude and associated likelihood of consequences determined, and the preference structure established, it became necessary to synthesize the information in a rational manner to evaluate the alternatives in light of the firm's business objectives. It follows from the axioms of decision analysis that the basis for this evaluation is the expected utility for each alternative. The selection of the most appropriate portfolio strategy begins with an evaluation of the available options. Recall that the scenario generation model was designed to analyze over 2500 portfolio scenarios. Table 3 shows expected value measures for each attribute of interest for ten of these portfolios and the firm's current portfolio which were computed in the scenario generation model. This part of the decision model also computed probability distributions for each of the attributes of interest (x_1, x_2, x_3, x_4). When modeling decisions under risk and uncertainty, it is important that a reasonably accurate representation of the range of outcomes, as well as their probability of occurrence is available. The minimum and maximum values for each attribute shown in Table 1 were generated in this portion of the model. Each portfolio analyzed represents a different mix of projects and participation levels for the drilling investments available to the firm.

It is apparent that other portfolios generated in the model achieved higher expected values on certain objectives than the firm's current portfolio. However, it is also easy to observe that no one portfolio represents the dominant choice in terms of achievement of *all* objectives. For example, Scenario #10 represented a substantial improvement over the current portfolio in terms of expected net present value and reserve replacement percentage. However, the current portfolio better achieved the objectives of maximizing return on investment and minimizing finding cost than does Scenario #10. Similarly, Scenario #7 possesses superior expected values on all dimensions except reserve replacement percentage than the current portfolio. However, the reserve replacement percentage for this scenario was significantly lower than the current portfolio (68% vs. 91%). It is also important to note that Table 3 *only summarizes the mean of the distribution for each attribute*. The decision maker, however, is more concerned with the relative uncertainty associated with each attribute's outcome. For example, though Scenario #10 has the highest expected reserve replacement percentage, it also has the highest variance in its reserve replacement percentage distribution.

The MAUT approach enabled the decision maker to incorporate his preferences about these uncertain outcomes and a measure of the relative importance of each objective. Altogether, 2500 portfolios were evaluated. These portfolios were evaluated on the basis of 4 attributes, and the value structure is quantified by the utility function u(x) for each attribute. In the case of uncertainty, the expected utility measure, $Eu(x)$, is [illegible]

TABLE 3. Portfolio scenarios are generated by the multi-objective decision model. A distribution of outcomes on each key attribute are measured as well as the expected value. Risk preference and a multi-objective approach are then incorporated into the analysis through the calculation of an expected utility measure.

	EXPECTED VALUE				
Portfolio	RRP (x_1) %	Find. Cost (x_2) $/BOE	NPV (x_3) $Million	ROI (x_4) ratio	EXPECTED UTILITY
Current Portfolio	91	3.66	197,900	1.802	0.53
Scenario #1	76	4.25	151,800	2.40	0.49
Scenario #2	122	4.71	253,500	0.950	0.59
Scenario #3	114	3.89	305,100	4.31	0.69
Scenario #4	104	4.35	392,300	1.35	0.68
Scenario #5	160	3.56	422,200	2.00	0.73
Scenario #6	141	4.10	226,400	6.31	0.48
Scenario #7	68	3.30	326,900	4.75	0.55
Scenario #8	105	3.12	368,200	1.65	0.57
Scenario #9	137	3.18	409,300	3.10	0.76
Scenario #10	226	4.51	528,300	1.55	0.69

mean of the distribution for each attribute. The decision maker, however, is more concerned with the relative uncertainty associated with each attribute's outcome. For example, though Scenario #10 has the highest expected reserve replacement percentage, it also possessed the highest variance in terms of the reserve replacement percentage distribution.

The MAUT approach enabled the decision maker to incorporate his preferences about these uncertain outcomes and a measure of the relative importance of each objective. Altogether, 2500 portfolios were evaluated. These portfolios were evaluated on the basis of 4 attributes, and the value structure is quantified by the utility function u(x) for each attribute. In the case of uncertainty, the expected utility measure, $Eu(x)$, is substituted for $u_i(x_i)$ in Equation 1, where:

$$u_i(x_i) = Eu(x_i) = \sum_{j=1}^{n} p_j u(x_j) \tag{3}$$

where x_i is the attribute of interest, i = 1,2,3,4, and p is the probability of outcome j for each attribute x_i, and the sum of $p_j,...,p_n$ is equal to 1.0. Outcomes (x_j) and associated probabilities (p_j) utilized in Equation 3 are based on the probability distributions computed on each attribute in the scenario generation model. Then, with Equation 1, our computed values of $u(x_i)$ from Equation 3, and the assessed scaling constants for each attribute, k_i, we are able to compute the expected utility for each portfolio alternative; this value is shown in the last column of Table 3.

The expected utility value represents a measure of overall preference by the decision maker for each portfolio, given the risk and uncertainty associated with each performance dimension. If the expected utility for one portfolio option is higher than that for another, the first should be preferred; thus, options can be ranked using their expected utilities. In the example in Table 3, we observe that Portfolio Scenario #1 has an overall expected utility value of 0.49 while almost all other portfolio scenarios possess higher utility values. This suggests that these portfolios were more preferred by the VP than Scenario #1. The information in Table 3 can be used to evaluate the desirability of each portfolio option. In fact, the project and working interest participation mix for Scenario #9, with an expected utility value 0.76, is the most appropriate mix of investments of all portfolios shown in this sample. This portfolio represents the most desirable decision strategy given the decision maker's tradeoffs among objectives and preferences toward uncertain or risky outcomes.

SENSITIVITY ANALYSIS

The important products of an analysis are its insights, which can best be provided by examining several sensitivity analyses on key decision and state variables. Using the multi-objective decision model it was easy to conduct a sensitivity analysis on critical uncertainties by varying inputs related to probability of success, reserve outcomes, product price, etc. for individual exploration projects. This changed the nature of the uncertainty on each attribute for individual projects, as well as the portfolio of projects. Changes in the risk characteristics may profoundly affect the expected utility analysis and the overall ranking of project portfolios. With regard to key decision variables, the maximum and minimum working interest options available for each project were varied. This enabled analyses of a different set of decision opportunities or portfolios and investigation of the effects on the optimal exploration investment strategy.

Sensitivity analysis was also conducted on the objective weights, k_i. Weights were adjusted to investigate the impact of changes in the importance of the firm's strategic objectives. Management was able to observe the effects of changes in objective weights on changes in the portfolio mix. To delete objectives, for example, simply required that the k_i value on that objective in the utility function be set to 0. This process of sensitivity analysis was helpful to the decision maker in understanding the impacts of objective setting and value tradeoffs among objectives, on identifying the appropriate investment strategy. Sensitivity analysis on individual preference functions, u_i, enabled management to examine the implications of different value judgments from different key individuals within the firm. This process provided insight about possible differences among decision making individuals in the company. In the case of substantial differences, the basis of these differences should be investigated and resolved.

DISCUSSION AND IMPLICATIONS

The multi-objective decision model was oriented around iterative application, with each use yielding guidance for new data and modification of critical model variables, i.e. risk preferences, objective weights, etc. The MAUT model incorporated a precise mathematical decision rule, that is, maximize expected utility. However, its effectiveness as a decision aid was related as much to its ability to provide decision makers insight into the effects of setting business objectives and risk policy on the investment choice process. The model's explicit and systematic nature of trading off conflicting objectives as well as measuring corporate risk preferences produced a more informed and rational decision process. This approach to capital allocation enabled the firm to avoid the casual and unsystematic handling of critical issues such as assessing risk attitudes and setting strategic corporate objectives when allocating scarce capital.

One of the key issues facing senior management in all companies and business sectors is effective management of the resource allocation process. Critical to this process is integrating the capital allocation policy with an overall business strategy. An effective means to facilitate this process is to clarify objectives and communicate a coherent risk policy for organizational decision making. In addition, the process of specifying objectives and utility functions is useful for identifying potential strategies and decision alternatives. A well-communicated set of corporate objectives and an organizational utility function make it easier for key employees to make appropriate decisions within their realm of responsibility. Well-articulated strategies, as well as systematic models of decision making, improve the quality of decisions and provide a solid framework for effecting a competitive business strategy.

REFERENCES

[1] Anandalingam, G., A Multiagent Multiattribute Approach for Conflict Resolution in Acid Rain Impact Mitigation, *IEEE Trans. Syst. Man Cybernet.* 19:1142-1153, 1989.

[2] Beley, J. R., Fleischauer, P., Keeney, R. L., Kirkwood, C. W. & Sicherman, A., Decision Framework for Technology Choice - Volume 1: A Case Study of One Utility's Coal-Nuclear Choice, EA-2153, Research Project 1433-1, *Interim Report*, Electric Power Research Institute, Pal Alto, CA, 1981.

[3] Bell, D. E., Consistent Assessment Procedures Using Conditional Utility Functions, *Operations Research* 27:1054-1066.

[4] Bodily, S. E., A Multiattibute Decision Analysis for the Level of Frozen Blood Utilization, *IEEE Trans. Syst. Man Cybernet*, SMC-7, 683-694, 1977.

[5] Byars, L. L., Strategic Management:Planning & Implementation, Harper & Row, New York, 1987.

[6] Corner, J. L., & Kirkwood, C. W., Decision Analysis Applications in the Operations Research Literature, *Operations Research*, 39:206-219.

[7] Cozzolino, J., Controlling Rish in Capital Budgeting: A Practical Use of Utility Theory for Measurement and Control of Petroleum Exploration Risk, *The Engineering Economist*, 25:161-186, 1980.

[8] DeNeufville, R, & Keeney, R. L., Use of Decision Analysis in Airport Development in Mexico City. *In Analysis of Public Systems*, A.W. Drake, R.L. Keeney and P.M. Morse (eds.), M.I.T. Press, Cambridge, MA, 1972.

[9] Dyer, J. S. & Lund, R., Tinker Toys and Christmas Trees: Opening a New Merchandising Package for Amoco Oil Company , *Interfaces* 12(6):38-52, 1982.

[10] Fishburn, P. C., Methods of Estimating Additive Utilities, *Management Science*, 13:435-453, 1967.

[11] Hackett, J. T., Concepts and Practice of Agency Theory with the Corporation. In E.I. Altman & M.G. Subrahmanyam (Eds.) *Recent Advances in Corporate Finance*, 163-172, Richard Irwin, Homewood, ILL, 1985.

[12] Hax, A. C., & Willig, K. M., The Use of Decision Analysis in Capital Investment Problems, In *Conflicting Objectives in Decisions*, D.E. Bell, R.L. Keeney & H. Raiffa (eds.) John Wiley & Sons, New York, 1977.

[13] Howard, Ronald A., "Decision Aalysis: Practice and Promise," *Management Science*, Vol. 34, No. 6:679-695, 1988.

[14] Huber, G. P., "Methods for Quantifying Subjective Probabilities and Multiattribute Utilities, "*Decision Sciences*, 5:430-458, 1974.

[15] Keefer, D. L., and Kirkwood, C. W., "A Multiobjective Decision Analysis: Budget Planning for Product Engineering," *J. Plln. Res. Soc.*, 29:435-442, 1978.

[16] Keeney, R. L., "Examing Corporate Policy Using Multiattribute Utility Analysis," *Sloan Management Review*, 17:63-76.

[17] Keeney, R. L., and Raiffa, H., "Decisions with Multiple Objectives," John Wiley, New York, 1976.

[18] Keeney, R. L., "Decision Analysis:An Overview," *Operations Research*, 30:803-808, 1982.

[19] Keeney, R. L., and McDaniels, T. L., "Value Focused Thinking About Strategic Decisions at BC Hydro," *Interfaces*, 22:6,94-109, 1992.

[20] Keeney, R. L., and Smith, G. R., "Structuring Objectives for Evaluating Possible Nuclear Material Control and Accounting Regulations, *IEEE Trans. Syst. Man Cybernet*, SMC-12, 743-750, 1982.

[21] Kirkwood, C. W., "A Case History of Nuclear Power Plant Site Selection," *J. Opln. Res. Soc.* 33:353-363, 1982.

[22] Lathrop, J. W., and Watson, S. R., "Decision Analysis for the Evaluation of Risk in Nuclear Waste Management," *J. Opln. Res. Soc.*, 33:407-418, 1982.

[23] Pratt, John W., "Risk Aversion in the Small and the Large," *Econometrica*, 32:122-136, 1964.

[24] Pratt, J. W., Raiffa, H., and Schlaiffer, R. O., "The Foundations of Decision Under Uncertainty: An Elementary Exposition," *J. Am. Statistical Association*, 59:353-375, 1964.

[25] Raiffa, H., "Decision Analysis: Introductory Lectures on Choices Under Uncertainty," Reading Mass: Addison-Wesley, 1968.

[26] Sarin, R. K., "Ranking of Multiattribute Alternatives with an Application to Coal Power Plant Siting," In *Multiple Criteria Decision Making - Theory and Application*, G. Fandel and T. Gal (eds.), Springer-Verlag, Berlin, 1980.
[27] Savage, L. J., *The Foundation of Statistics*, New York, John Wiley, 1954.
[28] Thompson, A. A., and Strickland, A. J., *Strategic Management: Concepts & Cases*, Irwin, Homewood, IL, 1992.
[29] Ulvila, J. W., and Snider, W. D., "Negotiation of International Oil Tanker Standards: An Application of Multiattibute Value Theory," *J. Opln. Res. Soc.*, 28:81-96, 1980.
[30] von Neumann, J., and Morgenstern, O., *Theory of Games and Economic Behavior*, Princeton University Press, Princeton, New Jersey, 3rd Edition, 1953.
[31] von Winterfeldt, D., "Setting Standards for Offshore Oil Discharges: A Regulatory Decision Analysis," *J. Opln. Res. Soc.* 30:867-886, 1982.

ENDNOTES

1. BOE represents barrel oil equivalent.
2. More details about the assessment of utility functions can be found in Fishburn (1967), Huber (1974), Keeney & Raiffa (1976), Bell (1979) and many other sources.
3. It is important to note here that the additive preference independence condition must be met before it is appropriate to utilize this form of utility function. Other, less strict conditions of preference independence, such as mutual utility independence, would suggest that more appropriate forms such as the multilinear (2-attribute case) or the mutliplicative form (3 or more attributes) should be utilized.
4. See Keeney and Raiffa (1976) for a more detailed discussion of the preference assessment procedure. 20

BIOGRAPHICAL SKETCH

MICHAEL R. WALLS is currently an Assistant Professor in the Division of Economics and Business at the Colorado School of Mines in Golden, Colorado. He has an undergraduate degree in geology from Western Kentucky University, an M.B.A. in finance and a Ph.D. in management from the University of Texas at Austin. Professor Walls' research interests are in the areas of strategic decision making, corporate risk management and business strategy. His current research efforts focus on the integration of decision science techniques and strategic planning for improving the quality of capital allocation decisions.