Chapter 2

How to Make Good Decisions

Change the decision-making process and cultural change will follow.

—Vince Barabba (1995)

2.1 Introduction

This chapter describes a scalable decision-making framework broadly applicable to most decision situations: with or without uncertainty, multi-objective or single objective, single decision or linked decisions, personal or business. It provides a framework for incorporating common decision-making tools, such as decision tree or influence diagram analysis, Monte Carlo simulation, expected values or utilities, and optimization. Its principles can be applied to analyses that span a range of times from less than an hour to months or years.

Real-world decision situations are usually complicated and poorly described. Frequently, it is unclear what the problem is and what decisions need to be made. To deal with complex real-world problems, decision analysis uses a process and framework that brings transparency, insight, and clarity of action to the decision maker.

Section 1.3.2 introduced one of the most useful distinctions in decision analysis: the difference between a good *outcome* and a good *decision*. The ultimate goal of the decision maker, and therefore the aim of this book, is good outcomes. However, at the time a decision is made, it is possible to control only the quality of the decision—the outcome also depends on the implementation and chance factors, as shown in **Fig. 2.1.**

The methodology developed in this chapter is focused on making high-quality decisions and is designed to lead to optimal outcomes if consistently applied. This chapter explores what comprises the "Deciding" box in Fig. 2.1. We start with an overview of the methodology. Then we define the elements that make virtually any decision hard, and consider some of the factors surrounding these elements. This is followed by three sections, each devoted to one of the key steps involved in one of the three main phases of the methodology. Finally, we summarize the key requirements for high-quality decision making and show how to assess the quality of a decision.

2.2 High-Level Decision Making Methodology

This section provides an overview of a methodology for making high-quality decisions, with the objective of maximizing the chance of good outcomes. This methodology is equally applicable to professional as well as personal decisions. For an organization,

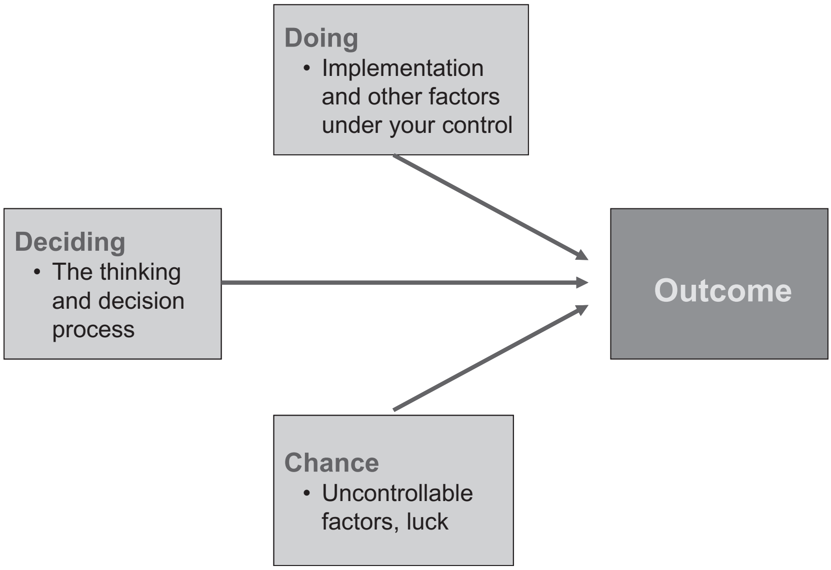

Fig. 2.1—Three factors that influence decision outcomes, modified after Russo and Schoemaker (2002). Reprinted with permission from Random House.

it is the glue that links the day-to-day work of technical and managerial staff with the goals and strategy of the organization.

The methodology incorporates traditional decision- and risk-analysis tools, such as influence diagrams, decision trees, probability analysis, Monte Carlo simulation, and optimization. Although the distinction between process and tools is not always clear, the remainder of this chapter emphasizes what may be called *procedural* tools, with the more analytical tools covered in subsequent chapters.

The procedure described in this chapter is not necessarily cumbersome or time-consuming. Indeed, the methodology contains explicit steps for simplifying and shortening the decision-making process. Depending on the nature of the decision and amount of information available, the elapsed time from start to finish may be as little as 30 minutes (e.g., to choose the best supplier for new drilling bits). On the other hand, the elapsed time may be several days, weeks, months, or more than a year for a major field development decision. In the latter case, only a miniscule fraction of the time expended is for implementing the methodology, the rest being for traditional data collection, technical analysis, and the like.

2.2.1 Overview. We developed the following methodology founded on the theory of decision science—integrated with our own ideas, findings, and experience. At a high level, the methodology consists of the following three main phases:

1. Structuring the decision problem (sometimes called *framing*). The main goal of this phase is to ensure that the right people are treating the right problem from the right perspective. Typical tools used in this phase are decision hierarchies, brainstorming, influence diagrams, strategy tables, and decision trees.

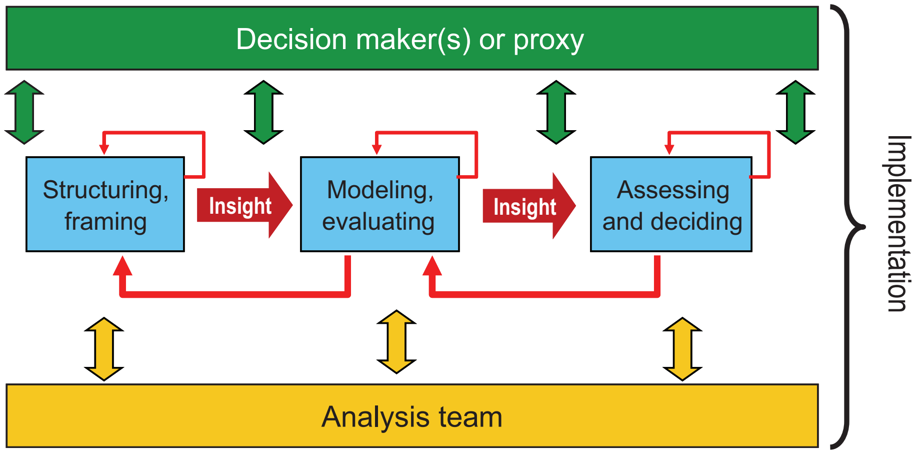

Fig. 2.2—High-level model of decision-making methodology.

2. Modeling the main elements of the decision problem and solving it. The goal for the modeling phase is to create understanding and insight and to communicate quantitative results. Tools used are influence diagrams, decision trees, Monte Carlo simulation, and optimization.
3. Assessing the model results and deciding. Most decisions are not made immediately after the modeling is presented. The results need to be tested, discussed, criticized, assimilated—and, most likely, revised. Typical tools are sensitivity analysis (tornado diagrams and spider plots) and tradeoff (or efficient-frontier) plots.

Fig. 2.2 shows, for a major decision, the relationship between these three phases and the main participants involved. It is an integration of a process developed by Stanford University and the Strategic Decisions Group (SDG), which Barabba (1995) termed a "dialogue decision process," using the analytical techniques of decision science developed by Howard and Matheson (1989), Raiffa (1968), Keeney (1992), and others. Our generic description considers the case in which the decision maker is not the analyst. However, the methodology is just as applicable to lower-level business decisions in which the analyst's immediate supervisor is the decision maker—and to business or personal decisions in which the decision maker and analyst is the same person.

As in many other spheres, good decision making requires a set of skills previously honed by deliberate practice rather than the result of natural talent or experience alone.* Decision makers and decision analysts alike need to acquire these skills, which currently are not provided within a typical petro-technical education. Consequently, entities seeking to improve organizational decision making should deliberately plan to

*Malcolm Gladwell (2008), drawing on research by Ericsson et al. (1993) and others, makes a persuasive argument that at least 10,000 hours of deliberate practice is required to achieve the level of mastery associated with being a world-class expert—in anything—even for individuals who are talented to begin with. Even if the goal is less ambitious than becoming world-class, significant deliberate practice is required to excel in decision making.

develop the required skills of the various participants, with explicit recognition of the role of *decision analyst.*

In some cases, the analysis team may not interact directly with the decision maker, but with an intermediary who can make a recommendation further up the chain of authority. In such cases, it is very important that the decision objectives are those of the real decision maker (as discussed further in subsequent sections).

A key aspect of making a high-quality decision is the incorporation of learning from previous decisions, which particularly impacts Phases 1 and 2, and therefore requires the previous decisions (and the processes and data used to reach them) to be recorded and available. Although not identified as an explicit step in the previous schema, documenting the methodology and eventual outcome of a decision is vital to improving future decisions.

Although the general flow of Fig. 2.2 is from left to right, the procedure is not linear. There are normally iterations, or feedback loops, both within and between the main phases as insight evolves. For example, early in a major decision-making study, we may wish to simplify the analysis by identifying which uncertainties really matter and therefore need to be modeled in detail later. Thus, the Modeling and Evaluation phase may involve the creation of a deterministic model, and the Assessing and Deciding phase may be a one-at-a-time sensitivity analysis using tornado plots (see Section 2.7.2).

As suggested by Fig. 2.2, there is regular communication and feedback between the main analysis team and the decision maker(s). In particular, it is recommended that formal review and approval be given at the beginning and the end of each phase, as indicated by the green arrows. This review and approval helps to ensure *buy-in* and alignment with organizational objectives, while preventing the main analysis team from pursuing potentially costly modeling approaches or solutions that do not have the support of the decision makers. It also means that the decision maker(s) will take responsibility for the adequacy of the analysis.

Parts of the methodology involve numeric calculations. However, the main value is *not* in the precision of the numbers generated, but rather is in the structured thinking, quantification, objectivity, and insight that this methodology engenders, along with the resulting transparency, record, and clarity of action. If the methodology is being followed merely because it is required, or there is over-focus on the numeric calculation aspects, its value is probably reduced. For some decisions, it may not be necessary to perform any numeric or analytical calculations. Merely following the structured process, combined with careful thinking about the main elements of the decision (see Section 2.3) may be sufficient.

The methodology is highly scalable and therefore adaptable to a time scale determined by the significance of the decision and resources available. We are not seeking some theoretical optimum that requires unbounded time and resources. Rather, we take a pragmatic approach, seeking good decisions given the constraints of time, resources, context, and materiality. However, we do propose that the validity of these constraints be critically assessed and not based on some preconceived idea of the "right answer." The notion of fit-for-purpose models is captured by the term "requisite model," as defined by Philips (1984): "A model can be considered requisite only when no new intuitions emerge about the problem." (For reasons described in Chapter 7, we prefer *insights* to *intuitions*). A fit-for-purpose model can be arrived at by cycling through the methodology shown in Fig. 2.2 until there is stabilization of the decision maker's objectives, preference among the alternatives identified, and beliefs about uncertainties.

2.3 Decision Elements

The first step in evaluating a decision situation is to identify its main elements, which requires a clear understanding of what constitutes an "element." The following five elements can be identified in virtually all decision situations:

- Alternatives (or choices) to be decided among
- Objectives (or criteria) and preferences for what we want
- Information, which may include data and is usually uncertain
- Payoffs (or outcomes, consequences) of each alternative for each objective
- Decision, the ultimate choice among the identified alternatives

The first three elements are sometimes called the "decision basis" (Howard 1988). A model of the relationship between these elements, and therefore of decisions in general, is shown in **Fig. 2.3.** Broadly, the objectives, alternatives, and information all contribute to the predicted payoffs and the alternative with the maximum payoff is chosen. Each of these elements is defined briefly in the following subsections and is then elaborated on in subsequent sections.

2.3.1 Decisions. In Chapter 1 defined a decision as a "conscious, irrevocable allocation of resources to achieve desired objectives." A good decision is an action we take that is logically consistent with our objectives and preferences, alternatives perceived, and information available. The decision is made at the point at which we commit to one of the alternatives.

As shown in **Fig. 2.4**, the current decision can be thought of as *strategic*, because it is made in the context of previous policy decisions and can result in future tactical or operational decisions. The term strategic is used in a relative, not absolute, sense. Therefore, the methodology proposed here is not restricted to decisions that are strategic in the common business usage of the word. For example, in the context of a field-development decision, the choice of drilling contractor may be considered tactical, whereas the choice of the number of wells is strategic. However, once development

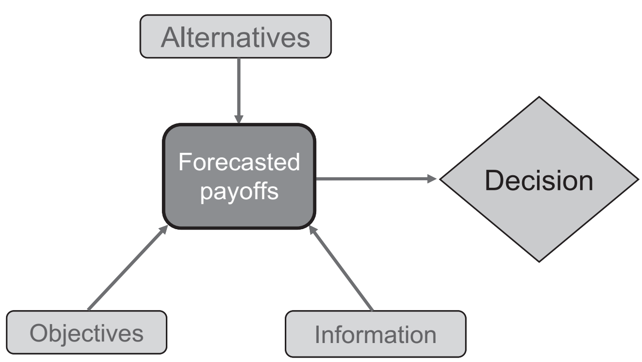

Fig. 2.3—Elements of a decision model.

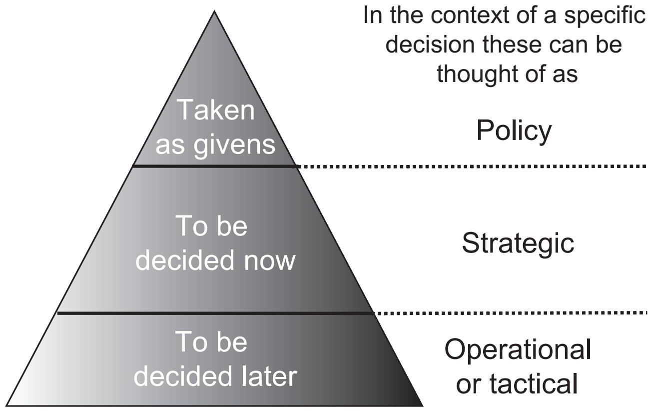

Fig. 2.4—Decision hierarchy—the middle band represents the decision(s) to be made now.

has commenced, the choice of drilling contractor becomes strategic, and the same methodology can be used.

All too often, the initial focus is on tactical, operational, or *how-to-do-it* decisions rather than on the underlying strategic or *what-should-we-be-doing* decisions. This erroneous focus can manifest itself in a rigid adherence to workflows, existing methods of problem solving, or a *let's-just-get-on-with-it* mentality:

> *Many are stubborn in pursuit of the path they have chosen, few in pursuit of the goal.*
>
> —Friedrich Nietzsche

Typically, strategic decisions require (and allow time for) considered thought, and are intended to create and maximize things of value to the decision maker. Thus, decisions in emergency situations, decisions for which there are prescribed routine operating procedures, reflexive reactions, or decisions of trivial consequence are not considered strategic in this context. Mackie et al. (2006) discussed relating an appropriate process to a decision type. One way to identify the key decisions is to elicit a short description of the problem, such as "the elevator pitch," to explain what the effort is all about in the small amount of time available during an elevator ride before you or an interested stranger have to disembark.

2.3.2 Alternatives (or Choices). A defining characteristic of a decision situation is that alternative courses of action must be available. There is no decision to be made if there are no alternatives from which to choose. For example, if the law mandates that a well is to be logged, whether or not to log is not a decision to be made (unless it is a decision about whether to obey the law). The terms *choice, alternative*, and *course of action* are used synonymously. We generally use—and prefer—the word alternative, because it implies the notion of being mutually exclusive.

Decision alternatives can range from the simple (e.g., drill at location A, B, or C), through the complex and sequential (e.g., field development), to those with extremely large numbers of alternatives (e.g., how to partition a budget, of which portfolio selection is a special case). Sometimes the choice is of *strategy*, which is a series of sequential decisions. However, rather than evaluate all alternatives for each component decision, a single alternative is chosen—one appropriate to the theme that defines the strategy. See Section 5.3.2 for a better description of strategies.

2.3.3 Values, Objectives, and Preferences

No man does anything from a single motive.

—Samuel Taylor Coleridge

It is impossible to choose rationally the best course of action in any given situation without having a clear idea of what the decision is intended to achieve. Therefore, an absolute prerequisite for rational decision making is to identify and state clearly a set of *objectives* by which the worth of each alternative is judged.

For each objective, we associate an *attribute* (measured with an appropriate scale) capable of quantifying how well the decision alternatives achieve the objective. Usually, there are multiple objectives of unequal importance, necessitating the assignment of relative weights or another technique to express the decision maker's *preferences* for the objectives. The identification of these objectives is often driven by the higher-level *values* (or evaluation concerns) of the decision maker (or the entity that the decision maker works for). **Fig. 2.5** shows how**—**taken together**—**the decision maker's values, objectives, and preferences form a *value tree* or *value hierarchy*. Its components are described subsequently.

- **Values.** Values are general, high-level statements of things that matter in the context of the decision. A value for a public corporation may be to increase shareholder wealth (as given by the fiduciary relationship between the shareholder and executive management). One element of this relationship is the "duty

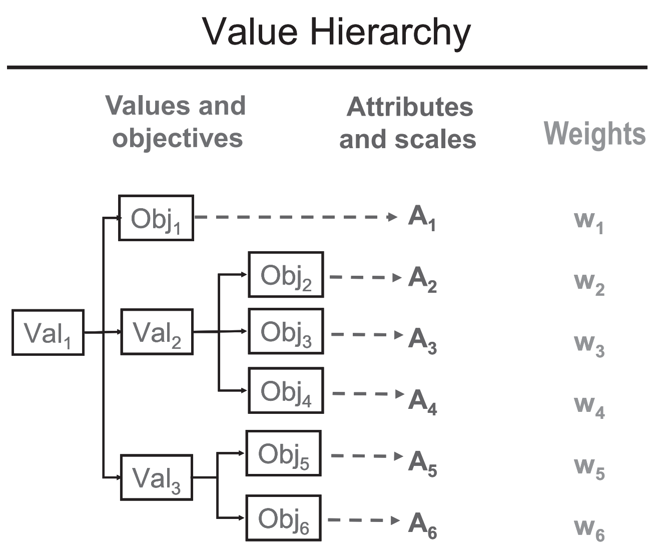

Fig. 2.5—Structure of a value hierarchy.

of loyalty," which requires corporate directors to "maximize the investors' wealth rather than [their] own" (Easterbrook and Fischel 1991), or to act in a socially responsible manner. For a national company, a value may be to increase the well-being of the country's citizens; and for a private company or individual, it can be anything important to them.

- **Objectives.** Objectives (sometimes called criteria) are usually verbs that describe preferred directions of movement (i.e., maximize or minimize) of quantities that reflect the high-level values. For example, an objective consistent with maximizing shareholder wealth (the value) may be to maximize economic worth. (The word *goal* is sometimes used synonymously with objective—here, we reserve the term *goal* to mean a specific level of an objective to be attained.) The primary purpose of objectives is to judge the relative merits of each decision alternative. A secondary purpose is to inspire the creation of alternatives. Although most oil and gas companies typically use several objectives in their decision making, maximizing net present value (NPV) is often sufficient to maximize shareholder value (Brealey et al. 2005).
- **Attributes.** An attribute is a measurement scale that can quantify how well a particular decision alternative meets a given objective. For example, NPV may be the attribute chosen to quantify the objective "maximize economic worth." An appropriate measure (i.e., attribute) is often obvious for simple, clear objectives. However, if the objectives are more complex or ill-defined, there may be more than one possible attribute (e.g., stock-tank barrels or reservoir barrels for oil volume). This possibility is especially true if the attributes are numeric scores that map to a verbal description of the degree of attainment of an objective.
- **Preferences.** When there are at least two objectives, it is necessary to state the relative desirability, to the *decision maker*, between the objectives. For example, is maximizing NPV more important than maximizing reserves? The impact of differing objective preferences can be accounted for by assigning a numeric *weight* to each objective. Better performance on one objective can sometimes be achieved only at the cost of decreased performance on another. (In this context, *preference* is not our preference, or attitude, regarding risk or for different levels of attainment within an objective, which will be discussed later.)

Importance of the Value Tree. A good value tree adds transparency to the decision-making methodology by making clear how the alternatives are to be (or were) judged. It may therefore aid in obtaining the buy-in of all involved in its implementation. It can also reveal a hidden agenda, which can be considered as a set of objectives and associated preferences not known to, or shared by, everyone involved. People with hidden agendas are not inclined to use such a methodology; or, if they do, they may make decisions that seem contrary to what the analysis suggests. Often, what appears to be a puzzling or irrational decision can become clear (i.e., rational) when the true objectives and weights of the decision maker are known. Similarly, arguments about the best alternative often involve not the understanding of each alternative and its likely outcomes, but, rather, the relative importance of the outcomes to different people.

The importance of specifying and agreeing on the objectives of the decision maker at an early stage cannot be overstated.

2.3.4 Information and Uncertain Events. We always have some information about factors that influence a decision situation—no matter how incomplete or uncertain that information may be. The information may be in the form of quantitative data, or it may be more qualitative or descriptive.

Normally, referring to uncertainty in decision making is in the context of specific *events* whose *outcomes* are unknown at the time the decision is made. In this context, the event may have already happened (e.g., the reservoir is filled, and there is an unknown original oil in place) or may be yet to happen (e.g., the number of hours it takes to complete a well). The difference between "has happened" and "yet to happen" is immaterial to decision making, except that, for an event that has already occurred, it may be possible to discover its outcome.

As noted in Chapter 1, uncertainty and knowledge are intimately linked. The extent of our knowledge about uncertain events is quantified using probability. To do so, we first need to identify all possible outcomes of the event (e.g., OOIP may take all possible values between 100 million and 900 million STB) and then assign probabilities to these possible outcomes. A common misconception is to think that we need (a lot of) data, in the form of measurements, to be able to assess probabilities. To the contrary, it is *always* possible to assess probabilities. As discussed in Chapter 3, probability quantifies our beliefs about the likelihood of an outcome. Those beliefs are constructed from our total knowledge of the situation and may or may not include measured data.

Finally, we need to know if the outcomes of several uncertain events depend on each other (e.g., if the first well is successful, then there may be an increased probability that the next one is also successful). It is necessary to account for any dependency.

Given the myriad uncertainties that exist in any decision context, it is important to identify which ones should be considered within the evaluation. This topic is discussed in more detail in Section 2.7.2, but here is a simple criterion: Only those uncertainties that have a material impact on an objective, and therefore the decision, should be included.

In our industry, unpredicted or surprising outcomes are often observed, even after having performed a probabilistic analysis. There are at least two reasons for this. First, is the failure to account adequately for all relevant uncertain events or to identify the full range of possible outcomes. (This issue is addressed in Chapter 7.) The second reason is a tendency to focus uncertainty analysis on only those events that we can model (or get information about), while ignoring those we cannot. Ignoring dependencies does not cause an unpredicted outcome, but, rather, it results in an erroneous estimate of the probabilities of the outcomes.

2.3.5 Payoffs. A payoff is what finally happens with respect to an objective, as measured on its attribute scale, after all decisions are made and all outcomes of uncertain events are resolved. For example, once a well is abandoned and the production profile, prices, and all costs are known, we may determine its NPV (at the point in time that the decision was made).

At the time that the decision is made, some of the payoffs may be known and therefore considered to be deterministic. For example, assume that "experience" is one of the objectives for the decision "choose a new production engineer," and it is measured by the attribute "number of years relevant employment." We are likely to be able to assess the payoff for each candidate from his or her resume. Similarly, when choosing between products or services, the payoffs often can be found in specification sheets and other supplier documentation.

However, because of uncertainty, the payoffs usually have to be *forecasted* in terms of *expected values*. In Chapter 3, we provide a strict definition of what this term means. For now, it is sufficient to think of an expected value as an *average* that takes uncertainty into account. For hydrocarbon project investment decisions, the forecasted payoffs are typically derived from the predictions of reserves, production, or economic models. These payoffs are computed as a result of performing Monte Carlo simulation (see Chapter 4) or decision tree analysis (see Chapter 5).

Planning Horizon. When determining a payoff, the distance into the future to which we should look is not always clear. Consider the objective of "maximize monetary value" as measured by NPV. Should we also consider the NPV arising from possible future investments made possible by the monies received from the immediate decision? If future investments are totally unrelated to the present one and may be funded from other sources, then we would not include these investments. However, if the present investment were an enabling one (e.g., processing facilities that may make currently uneconomic satellite fields viable), then we include it.

The distance into the future for which we incorporate subsequent decisions and uncertain events is termed the *planning horizon*. It is a judgment call based on the analyst's experience and knowledge of the decision situation, tempered by practicality. It should be chosen such that later events and decisions are included only if significantly impacted by the immediate decision.

2.3.6 Challenges and Issues Surrounding Decision Elements. The challenges surrounding the decision elements are presented in **Fig. 2.6.**

We are now able to place into context some of the items identified in Chapter 1 as making decisions "hard." Fig. 2.6 is a fairly complete high-level model of a generic hard-decision situation.

Ambiguity and Conflicts in Our Objectives. We are not sure exactly what we want or of the relative importance of each objective. We may not even know who the real

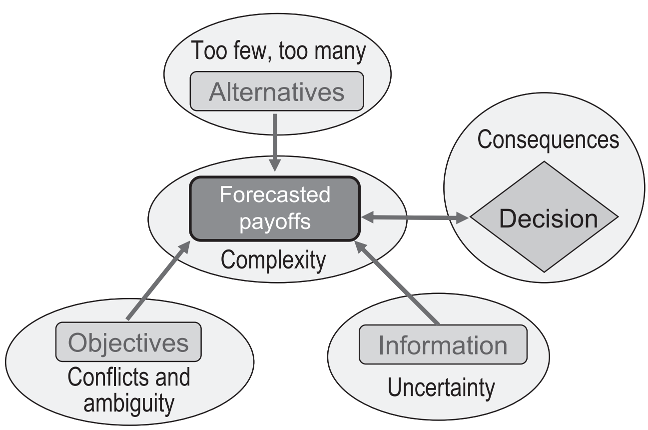

Fig. 2.6—Common factors or challenges surrounding decision elements.

decision maker is, and therefore whose objectives to use. Sometimes, attainment of one objective can only be achieved at the expense of another, such as maximizing current production vs. ultimate reserves, or maximizing return and minimizing risk.

Incompleteness of Our Alternatives. We may not have discovered all available choices, either because there are too many to enumerate or, more commonly, because we have not thought of all possibilities. The search for value-creating alternatives is a key part of any decision making, and by using processes ranging from simple heuristics to extensive group exercises, companies can stimulate the creativity needed to generate good alternatives. The failure to uncover all viable options can result in value loss. The decision can never be better than the best alternative identified.

Too Many Alternatives. Many problems present a bewildering number of alternatives, simply because choices must be made in several decision areas, and each decision area has several possibilities to choose from. The number of possible combinations increases rapidly with the number of decision areas. Creativity exercises may have dramatically increased the number of possible alternatives. The challenge is to not only pick a subset of alternatives to make the analysis feasible but also to create alternatives that are sufficiently different, so that the analysis is creative (see Section 5.3.2).

Uncertainty Surrounding Information. The pervasiveness of uncertainty has been discussed previously. Uncertainty in technical and commercial factors feeds through into uncertainty in the forecasted payoffs, which is the prime information used to make the decision. Assessing these uncertainties is one of the most important—and sometimes most difficult—jobs of the engineer or geoscientist.

Complexity in Assessing Payoffs. The number of alternatives, number of objectives, quantity of data, and uncertainty affect the complexity of the decision model required to evaluate the payoffs (excluding the complexity involved in associated technical analyses). The complexity is increased if there are dependencies in the system: between the immediate decision and other decisions being evaluated, between the immediate decision and subsequent contingent decisions, between the outcomes of uncertain events, or between pieces of information that can help predict the outcomes of the uncertain events.

Albert Einstein's declaration: "Keep the model as simple as possible—and no simpler" is also the basic rule of decision analysis. For any model used, the primary criterion to assess the payoffs has to be precise enough to distinguish between the alternatives. Large value swings caused by uncertainties outweigh the precision of the model. The iterative nature of the decision-making methodology enables successive refinement of the model; therefore, it does not have to be "perfect" the first time it is used. A common comment is, "The model has to be complete and detailed enough to convince the managers of its usefulness." Such logic is poor justification for building an overly complex model that does not contribute to the goals of transparency, insight, and clarity of action. A more reasonable justification is that, in some instances, it is not possible to assess the importance of a factor without modeling it.

Consequences of the Actual Payoffs. The final outcome of the decision may have different consequences for different people, and consideration of those consequences can impact the analysis. Consider a personal example. Suppose you are nearly broke but would like to take a friend out for a meal and then to the cinema. You bet your last few dollars on a game that gives you USD 100 if you win. If you lose, your situation does not change very much, but if you win, you have company and an evening's entertainment. On the other hand, a multimillionaire may gain insufficient satisfaction from an extra USD 100 to even justify playing the game. Similarly, the payoff of a business decision may have important consequences for you and your career, but not necessarily for the shareholders or for the company as a whole. Thus, the significance of the payoffs is greatly dependent on the decision maker's context.

The decision-making methodology proposed in the following sections is designed to deliver good results for decision problems characterized by the model shown in Fig. 2.6, even when considering the previously discussed challenges.

2.4 A Decision-Making Methodology

Now that the elements of a decision problem are defined, and some of the challenges that make decisions hard are identified, we more fully develop the methodology described in Section 2.2.

A *good decision* is defined as "an action we take that is logically consistent with our objectives and preferences, the alternatives we perceive, and the information we have" The methodology is a series of steps designed to deliver such a decision. The three main phases, described in subsequent sections, are broken up into eight sub-steps, illustrated in **Fig. 2.7,** as follows:

- Phase 1—Structuring (Framing)
  1. Define the decision context (decision, decision maker, and feasibility).
  2. Set the objectives (criteria) by which each alternative will be evaluated and identify any conflicts between the objectives.

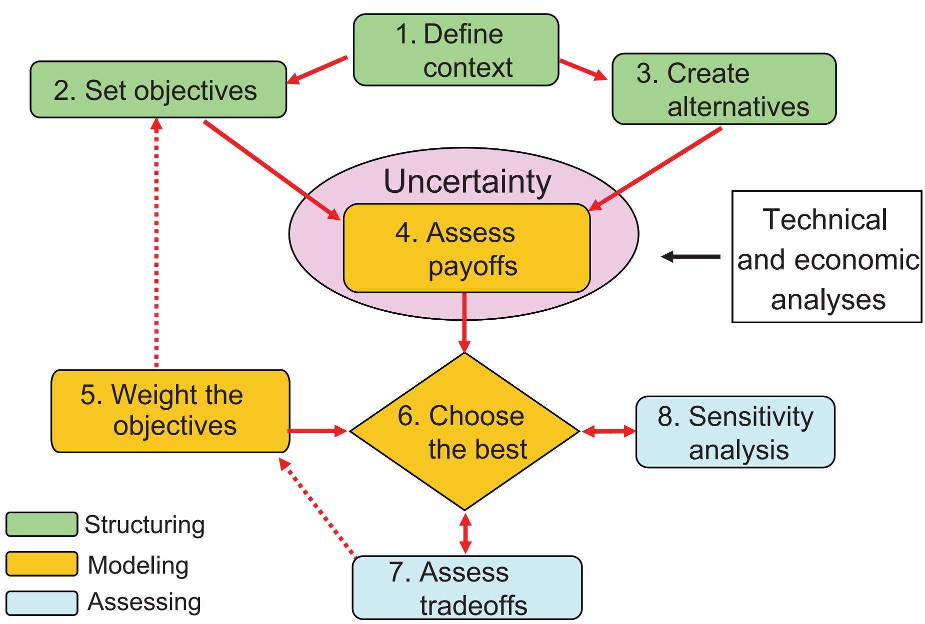

Fig. 2.7—Diagram of steps in decision-making methodology.

3. Create, or identify, the alternatives (choices).

- Phase 2—Modeling (Evaluating)
  4. Calculate the expected payoff of each alternative based on how well it meets the objectives (as measured on their attribute scales).
  5. Weigh the objectives according to their relative importance in distinguishing between the alternatives.
  6. Calculate an overall weighted value for each alternative, and provisionally select the best – the one that provides the highest value.
- Phase 3—Assessing and Deciding
  7. Assess tradeoffs between competing objectives.
  8. Perform a sensitivity analysis to test the robustness of the decision to the information that produced it.

Before proceeding, we re-emphasize two points. First, the methodology is highly scalable and therefore adaptable to the resources and time available (as determined by the significance of the decision). Second, although parts of the methodology involve numeric calculations and analytical procedures, the main value is not in the *precision* of the numbers generated but in the structured thinking, objectivity, and insight that the methodology engenders, along with the resulting transparency, record, and clarity of action.

How can it be determined whether a good decision was made or if the process leads to one? We explained that because of uncertainty, the outcome of any one decision cannot be used for this purpose. Instead, we must assess quality by how well the methodology has been or is being implemented. Section 2.8 describes a procedure for doing so, based on a series of questions.

The following sections identify several analytical decision-making tools and indicate which parts of the methodology each enables. However, descriptions of the actual tools are deferred to later chapters.

2.4.1 Implementation, Recording, and Learning. Although this book is not a detailed implementation, or a "how-to" guide, we briefly describe the benefits of using spreadsheets as a simple means to implement and document the methodology.

Apart from being able to conduct numerical calculations, a well-commented spreadsheet is valuable because it provides a concise, auditable record of why a particular decision was made—in the context of the analysis, factors, and information considered. This record is necessary both to enable learning through subsequent "look-backs" and to avoid the hindsight bias whereby the quality of a decision is judged using information available only after the decision was made (e.g., the outcome or revision of what was known and considered at the time). When reading through the following details, it may be helpful to have in mind a structure for Steps 2 through 6 similar to that shown in **Fig. 2.8.**

2.5 Phase 1: Framing or Structuring

The goal of the first phase is to identify and structure the relationship between the main elements of the decision problem. It is arguably the most important phase, because all successive phases depend on it. When something goes wrong in analyzing a problem, the roots of the difficulties often lie in the problem structure. Similarly,

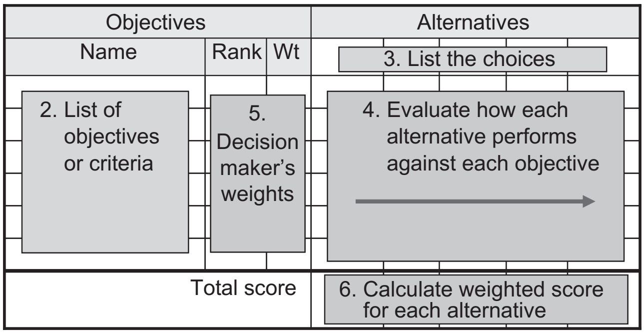

Fig. 2.8—Typical spreadsheet structure for recording and evaluating Steps 2 to 6.

when a problem is exceptionally well analyzed, it is usually because the analysis was well structured and framed from the beginning. The first step is to identify the decision context, which then is used as a frame of reference within which to identify the alternatives (Step 3) and to have specified objectives used to judge their relative value (Step 2).

The insights and clarity gained from this part of the methodology may even be sufficient to solve the decision problem without further work, which provides an opportunity to create value and mitigate risk. Conversely, producing a great answer to a poorly framed problem or opportunity is useless. Decision makers report spending too little time on this phase (Russo and Schoemaker 2002). The natural inclination and background of many geoscientists and engineers is to focus on information gathering, interpretation, model building, and analysis. Conducting the framing phase inadequately may lead to the following:

- It is unlikely that radically new ideas or solutions will emerge once you (or the team) are in the "nitty gritty" of evaluation.
- You will not achieve support for the decision.
- You may bring a good answer to the wrong problem.
- You will not be protected from the "curse of hindsight."

Tools that enable this part of the methodology include decision hierarchies; brainstorming; influence diagrams; decision trees; strategy tables; and strengths, weaknesses, opportunities, and threats (SWOT) analysis. Perhaps the most important *tool* is an open and imaginative mind. A good first step is to simply create lists of the main decisions, objectives, and uncertainties. The decision hierarchy, described in Section 2.3.1 helps to provide focus on the immediate decisions through avoiding distraction by later operational decisions or policy decisions already made. *Decision trees* and *influence diagrams* clarify the relationships between the main decision elements, although both tools have uses beyond structuring. A full discussion of decision trees can be found in Chapter 5, with additional applications in Chapter 6.

2.5.1 Step 1—Defining the Decision Context. The decision context is the setting within which the decision occurs. Common errors are to analyze the wrong problem or analyze the correct problem in an overly complicated manner.

Defining the context helps to set appropriate objectives and identify relevant alternatives. Suppose you are considering the decision "choose a new job." If you dislike your current career or lifestyle, the context should be oriented toward choosing a new one. However, if you like the occupation—but dislike your current employer, coworkers, conditions, etc.—then the decision is in the context of finding a new employer. The decision is the same in both cases, but the context is different. Furthermore, it is the context that is likely to determine the different objectives and alternatives. Subsequently, we discuss four aspects of determining the decision context.

Decision. Just because it may sound trivial, it does not make identifying the *real* decision any the less important. For a decision to exist, there must be a choice—engaging in an activity is not a decision. Thinking in terms of requests or opportunities for resource allocation (i.e., time, money) can help identify the decision. Decision situations are generally one of two types: a choice among known alternatives, or problem solving to create or identify alternatives. (The word *problem* in *problem solving* is not meant to imply a negative situation, but a complex one, such as how to best exploit an opportunity.) The type of decision determines the order in which Steps 2 and 3 are conducted. In either case, the decision hierarchy, illustrated in Fig. 2.4, can help to identify and exclude decisions already made (i.e., the givens) and any later implementation decisions that have no impact on the current decision. This decision hierarchy often produces a series of sequential decisions that impact materially on the optimal choice for the main decision. For example, if deciding between different development concepts [e.g., floating production storage and offloading (FPSO) or tension leg platform (TLP)], related decisions surrounding number of wells, processing capacity, etc., are important. Furthermore, how some uncertain events are resolved may bring about different subsequent decisions. In this case, a good tool for structuring the logical relationships between the various decisions and uncertainties is a decision tree, as discussed in Chapter 5.

Decision Maker. Identifying the decision maker(s) is important, because it is *that person's* objectives and preferences that are required (and in the case of a corporation, the decision maker's objectives should be aligned with those of the owners). In most cases, it is clear who the decision maker is. For personal decisions, it is obviously *you.* In a work context, it is often you or your manager. However, in some situations, it is not at all clear, particularly for complex decisions in large organizations in which many parts of the organization may be contributing to the ultimate decision. A key test that identifies the real decision maker is that the person is capable of assigning the resources required to implement the decision. If you are not that person, then you need to determine the decision maker's objectives or narrow the context of the decision for you to become the decision maker.

Ideally, the decision maker should be as far down in the hierarchy as possible, consistent with being aware of any wider context to the decision (i.e., corporate strategy, dependent decisions, etc.). The position of the decision maker and his or her relationship to the analysis is discussed in the next section within the context of setting values and objectives.

Feasibility. The definition discussed here does not refer to the feasibility of the ultimate decision you make, but to whether you or the analyst team have the time and resources needed to perform the evaluation required to make the decision or recommendation. If not, either additional resources should be sought or the problem narrowed to one that is feasible with current resources. If the decision maker is not agreeable to either of these alternatives, then the situation should at least be documented, and the decision maker should acknowledge the concerns in writing.

Assumptions and Constraints. Any constraints or assumptions should be identified, critically assessed, and recorded. By "critically assessed," we mean they should be challenged and their validity established. Sometimes, artificial constraints arise, because someone either prejudged the "right" answer or restricted the problem by specifying the list of alternatives. Doing so can be detrimental, because it generates a *choose between* rather than *value-creation* focus. Generally, if constraints must be imposed, reduce them to the smallest acceptable number, and consider their relevance. A special type of constraint is a non-negotiable policy within which the decision is to be made, such as, "We are a frontier exploration company." In the context of choosing between exploration opportunities, this constraint may be a reasonable constraint. If the decision is about company strategy, it is not a reasonable constraint.

2.5.2 Step 2—Objective Setting. The identification and setting of appropriate objectives is a crucial part of a good decision-making methodology. The ultimate goal of this step is to generate a set of *appropriate* objectives and their associated attribute scales with which to measure the value created by the different decision alternatives. (See Section 2.3.3 for a definition of these terms.)

As previously noted, it is impossible to rationally compare alternatives without knowing what they are designed to achieve. Objective setting is achieved by developing a *value tree* (see Fig. 2.5) used for the following:

- Guide information collection.
- Ensure that the decision is consistent with the overall aims of your organization. (*Organization* here refers to a public, private, or state company or entity.)
- Help create or identify alternatives (if not prespecified).
- Facilitate communication and buy-in.
- Evaluate the alternatives.

The value tree is developed by working from high-level values down to specific objectives. The procedure for accomplishing this development is designed to help remove the ambiguity that surrounds objectives and to identify conflicting objectives.

Depending on the scope of the decision and its context, as indicated in **Fig. 2.9,** the ultimate decision maker may be separated from the analysts conducting the decision evaluation. The greater the number of levels in the hierarchy between analyst and decision maker, the greater the scope for misalignment between their values and objectives, and the objectives actually used in the analysis.

The decision makers, irrespective of their position in the hierarchy, should have an *as-direct-as-possible* specification of the objectives, as shown by the green lines in Fig. 2.9. If it is impractical for the decision makers to directly specify objectives, then they should specify these objectives as far down in the hierarchy as possible, as indicated by the orange lines in Fig. 2.9. The worst case is indicated by the red lines whereby intermediaries modify values or objectives they receive from further up the hierarchy. There should be no place for modifying specific objectives or values. However, it may be reasonable for intermediaries to *interpret* values into specific objectives

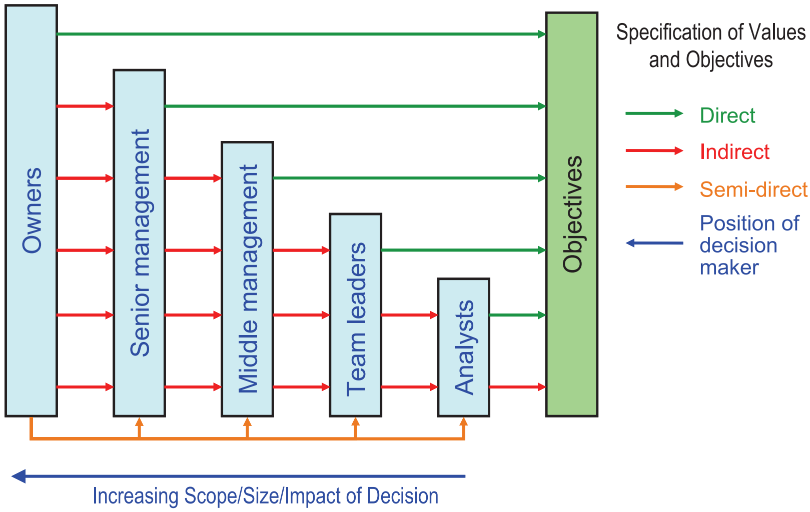

Fig. 2.9—Model of specification of values and objectives.

on which it is important not to *overlay* their own objectives or values, such as personal attitudes toward levels of risk. An appropriate incentive policy is the key to ensuring alignment down the hierarchy.

The sub-steps required to develop the value tree are outlined subsequently (with the exception of determining weights, which is covered in Step 5, Section 2.6.2). For this discussion, we assume a *problem solving* decision context in which the possible solutions (i.e., decision alternatives) are yet to be identified. If this context is not the case, the order of Steps 2 and 3 should be reversed.

Identify Values. If the decision is complex, high-level, or broad in scope (e.g., a major field development decision or what you would like for a career), the first step should be to identify the main values, concerns, or issues the decision is designed to address. Values are things that matter to you and are general in nature, such as the following examples:

- Be profitable.
- Be safe.
- Create value.
- Have fun.
- Be wealthy.

In a work situation, especially if the decision context is broad, the values (and maybe even the objectives) are specified by your organization. In a public corporation, these values may be the publicly stated corporate values. If the context is more limited (e.g., you or your manager is the decision maker), it may be more appropriate to develop your own set of values, consistent with your organization's overall values. If the context is personal, the values are things that matter to you.

Set Objectives. Objectives are specific, measurable things that you want to achieve and that should be consistent with the decision maker's broader values. They are usually of the form “maximize X” or “minimize Y.” The first step is to develop a potential list. Keeney (1994) provided a list of helpful questions for doing so. If the decision context is not one of problem solving, and you are sure that all alternatives have been identified, then you can use inspection of the alternatives (Step 3) to help set the objectives. Examples are choosing among a known set of applicants for a job or tenders for a contract. Once a list is developed, the next step is to distinguish between fundamental and means objectives.

- **Fundamental Objectives.** These objectives identify basic reasons why the decision is important to you. For example, maximize NPV or reserves. One way of discovering fundamental objectives is to continually ask, “Why is this important?” When the answer—in the context of the decision—is along the lines of “Because it is,” “This is why we are making the decision,” or “This is what I care about,” then a fundamental objective is reached. In the context of decision making in a company, higher-level objectives may be derived from key performance indicators in a “balanced scorecard.” As far as practical, fundamental objectives should be independent of each other and can be organized into a *hierarchy*. For example, the objective of “maximize profit” may be subdivided into “minimize cost” and “maximize revenue.” The lowest-level objectives in the hierarchy are used to define the payoffs of the alternatives.
- **Means Objectives.** Means objectives are possible ways of achieving the fundamental objectives, but are not in themselves ends or reasons for making the decision. For example, “Motivate team members” may be a means toward the end of “Maximize value.” Means objectives can be identified by asking questions, such as “How can we do that?” Because a single means objective may contribute to multiple fundamental objectives, these objectives are organized as *networks* rather than hierarchies. Means networks are a good source for generating possible solutions (alternatives) to the decision situation.

Because of the often indirect nature of this step, quantitative studies ideally should be undertaken to prove that a relationship does indeed exist between fundamental objectives and values, thus ensuring that maximizing/minimizing objectives actually results in maximizing the decision maker’s value. For example, in a company setting, performance measures *known* to drive owner value are required.

Define Attribute Scales. The next step defines scales for measuring the achievement of objectives. There are two types of scale: natural and constructed.

A *natural* scale is a commonly understood quantity measured or calculated objectively. Examples are reserves in STB, NPV in dollars, and production rate in STB/D. If objectives are defined precisely, an appropriate natural scale may be implicit. Otherwise, there may be a choice of scales (e.g., Fahrenheit or Celsius to measure temperature).

A *constructed* scale is required for objectives without a commonly accepted measure, such as the reliability of a potential equipment supplier. A constructed scale is typically defined by a range of integer values associated with verbal descriptions that reflect increasing *levels* of achievement of the objective. At the simplest level, it may be no more than assigning numbers to words, such as “high,” “medium,” and “low.” Constructed scales are usually specific to the decision at hand; and, if the decision has a broad context, they are often used to limit the number of objectives by combining several into a single, broader objective. The level of detail depends on the nature of the decision, the time available, etc. For example, "minimize environmental impact" may be measured using a constructed scale from 1 to 5, where

1 = no impact
2 = removal of 2 km^2 of agricultural land
3 = removal of 2 km^2 of wetland habitat that contains no endangered species
4 = removal of 2 km^2 of wetland habitat that contains at least 1 endangered species
5 = removal of 2 km^2 of wetland habitat that contains species unique to that location

When generating a constructed scale, it is usually best to first define the levels in words, and then associate numbers to the levels. Assign 0 to the status quo if there is one (e.g., for a "hire replacement geologist" decision, set 0 to the level that describes the ability of the incumbent). Negative numbers depict levels worse than the status quo, and positive numbers depict levels better than the status quo.

Attribute scales can also be categorized as *proxy* or *direct*. A *proxy* scale is one that correlates with the objective, whereas a *direct* scale is a direct measure for the objective. For example, in a public corporation, NPV in dollars is a frequently used natural scale that is a proxy for measuring shareholder value (for which a direct measure consists of a share price and dividends). The Standard and Poor's (S&P) 500 is a constructed-proxy measure for the United States' economic health. The choice of scale type is commonly between natural-proxy and constructed-direct.

If the alternatives are known, the range of a scale can be determined by inspecting the minimum and maximum values of all of the alternatives (e.g., five job candidates whose experience ranges from 3 to 15 years). For purchasing decisions, this information can be derived from product-specification documents. On a personal front, consumer magazines (e.g., *Choice, Which*, and *Consumer Reports*) are a ready source of information.

Review. The final step is to check the whole value tree for adequacy. Keeney and Raiffa (1993) listed the following five criteria for checking:

1. **Completeness:** No significant issues of concern are missing.
2. **Operationality:** Objectives are clear enough to be able to assess the alternatives.
3. **Decomposability** (independence): Performance of an alternative on one objective can be judged independently of other attributes. (This criterion is often hard to achieve.)
4. **No redundancy:** No objective is a *rephrasing of another;* otherwise, it can lead to excess weighting.
5. **Minimum size:** Do not subdivide more than necessary for operationality and decomposability, and remove objectives incapable of distinguishing between alternatives.

Multiple Objectives. There are three main challenges associated with having multiple objectives. First, multiple objectives imply multiple attribute scales. How then do we compare the value of, for example, dollars with barrels or with a safety *score?* This problem is addressed in Step 4. Second, the decision maker may have different preferences for achieving each objective. For example, maximizing economic benefit may be twice as important as maximizing next year's production rate. This problem is addressed in Step 5. Third, conflicts may exist in which increasing the level of achievement on one objective, decreases achievement of another objective. For example, maximizing current production rate may reduce ultimate recovery. This problem is addressed in Step 7.

Although the problem of objective preferences is addressed in detail in Step 5, at this point, to help with the forthcoming step of identifying alternatives, the decision makers should express their relative preference between the objectives by using a simple weighting scheme. That is, they should assign each objective a number between 0 and 100 (or 0 and 1) that indicates their relative preference for achieving them. This is a "naïve" weighting scheme that, while useful for helping to create desirable alternatives, is generally not suitable for choosing between those alternatives (for reasons that are explained in Section 2.6.2).

2.5.3 Step 3—Identifying Alternatives. Assuming that the decision context involves a problem to be solved or an opportunity in which to take advantage, the creation or identification of viable alternatives (i.e., choices, solutions, options, and courses of action) occurs as the third step.

A decision can never be better than the best alternative identified. Here, the decision evaluation methodology can be used to create value. If value-maximizing alternatives are not identified now, they are unlikely to emerge once the modeling-and-evaluation phase begins. Consequently, a goal should be the generation of substantially different alternatives.

Examination of high-level values and objectives (see the "Set Objectives" portion of Section 2.5.2) is one way of creating alternatives, using the simple weighting scheme, described previously, to ensure focus on identifying alternatives that can deliver what the decision maker really values. For example, create a hypothetical ideal solution that performs at the maximum level on your fundamental objectives, or create one ideal alternative for each objective. These hypothetical alternatives, which are likely to be impractical, can then be used as a starting point for developing realistic alternatives. An opposite approach also may be useful. Start with a known alternative, and ask how it can be improved to perform better against the objectives. Yet another way of creating alternatives is to examine the means-objective network, which is essentially a "how to" for achieving the fundamental objectives.

Creativity is especially important when trying to find ways of managing uncertainty. For example, delaying revenues is often assumed to cause value loss because of the economic concept of the time value of money (the longer time until receipt of a dollar, the less its value). However, the value of delaying a decision in order to obtain more information, and thus make a better decision, may outweigh the loss in time value. Likewise, adding flexibility into the execution of a project in order to respond to the resolution of uncertain events may outweigh the direct cost of the flexibility and any delay it may involve. These ideas are expanded in Chapter 6, under the topics of Value of Information (VOI) and Value of Flexibility (VOF).

This identification of alternatives is often conducted in a group setting. Individual communication skills and the facilitation of a creative atmosphere are essential. Group members need to actively listen to each other's suggestions, and negative judgmental comments (i.e., bad, crazy, stupid, unrealistic, etc.) should be banned. One person's “stupid” idea may inspire another person’s “great” idea, which helps to create a range of very different alternatives rather than variations on a theme.

If the decision is fairly straightforward and all possible choices can be identified easily (e.g., there are only three possible electric submersible pumps from which to choose), then it can be helpful to make this step the second step, and use the resulting list of alternatives to help specify objectives (Step 2). Remember, the purpose of the objectives is to judge the “goodness” of the various alternatives.

Sometimes, the decision situation involves choosing among alternative strategies made up of a series of sequential or related decisions. In this case, the number of combinations can quickly become unmanageable. Strategy tables (see Section 5.3.2) are recommended for developing a manageable subset of the alternatives to be evaluated.

2.5.4 Summary and Remarks. Identification of the decision maker and a clear exposition of the decision context are required for the efficient and successful execution of the evaluation procedure. The importance of specifying and agreeing on the *objectives of the decision maker* at an early stage cannot be overstated. Without specified values or objectives, it is impossible to rationally decide the best choice, solution, or course of action—and there is little point in continuing with the decision-analysis methodology we propose. If there are intermediaries between the decision makers and the analysts, it is necessary to ensure alignment throughout that hierarchy.

The skill, experience, and knowledge of the people involved in the analysis are the source of value creation through identification of alternatives, particularly in discovering options to manage uncertainty by mitigating its downside or exploiting its upside.

At the end of this phase, if you are participating in a decision in which you are not the decision maker, the analysis-to-date should be reviewed with the decision makers and their formal approval sought for the adequacy of the context, specification of objectives, and identification of alternatives. This step not only helps to ensure an optimal decision and provides valuable learning information once the outcome is known, but addresses any second-guessing in the event that a bad outcome is caused by chance.

2.6 Phase 2: Modeling and Evaluating

The goal of this phase is to reach a preliminary decision based on the alternatives identified, the objectives set, and the decision maker’s preference for the relative importance of those objectives. The first step (Step 4) makes an assessment of the extent to which each alternative helps achieve each objective (i.e., its payoff). The second step (Step 5) determines the decision maker’s relative priority for the objective. The final step (Step 6) combines the performance against each objective into an overall score for each alternative. Here, *modeling* refers to modeling the decision, not to technical modeling activities that feed information into the decision.

2.6.1 Step 4—Assessing Alternatives Against Objectives. The goal of this step is to make a relative comparison of the merits, or *value*, of the alternatives toward achieving objectives. (This should not be confused with the decision maker’s broad “values” described in the “Identify Values” portion of Section 2.5.2.) There are two main tasks to be completed. The first is the development of a *payoff matrix* (sometimes called a *consequence matrix*) that quantifies how well each alternative *scores* on the objective attribute scales. The second task is to determine how much value is derived from these scores.

Scoring Alternatives. As defined in Section 2.3.5, a payoff is the extent to which an objective is met after the decision(s) is made and the outcomes of any uncertain events are resolved. Usually, the payoffs are not known in advance, are subject to uncertainty, and must be estimated or forecasted. Subsequent chapters cover the assessment and modeling of uncertainty in detail using tools such as decision trees or Monte Carlo simulation.

Generating the data for this matrix is the primary role of technical, economic, and commercial studies (including any models and interpretations that underlie these studies). This is the point in the decision analysis where the results of such studies are incorporated. For example, consider a decision about where to drill an infill well. **Fig. 2.10** shows the expected payoffs of four alternative well locations for each objective attribute.

Pause to think for a minute. If you ever wonder why you are doing something or you want some guiding context for it, reflect on the payoff matrix. Directly or indirectly, the jobs of most technical and professional staff in an organization are related to identifying alternatives and assessing their payoffs, with the decision makers being largely responsible for specifying objectives. Remember, however, that not all decisions are about where to drill wells. You may be deciding on, for example, which drilling contractor to hire—or, if you are a service company, how to set your pricing and terms. The point is that no matter what your job or your organization, you should have a decision-driven focus. You should be able to trace the linkage between your work and the payoff matrix, or your supervisor should be able to show it to you. If not, you or your supervisor should at least query the relevance of the work you are doing. What if there is not an explicit payoff matrix that all can see? At an absolute minimum, you should be able to know to which decision(s) your work is contributing and the objectives by which those decision(s) will be determined.

Now, having obtained the payoff matrix, which summarizes the key elements of the decision, how do we use it to make the decision? Start by recognizing that the role of the objectives needs to change from one of helping to *identify* good alternatives to helping to *choose* between alternatives. This change of role has practical consequences that can lead to considerable simplification of the problem. (It also has consequences for the appropriate weighting of objectives and how that weighting interacts with the scores, which is discussed in Section 2.6.2). First, any objective that does not distinguish among the alternatives, *no matter how important*, should be removed from the list. For example,

	Alternative Well Locations			
Objective Attributes	A	B	C	D
NPV, USD million	37	54	64	43
Safety, 0–10 scale	7	6	3	8
Reserves, million STB	2.5	2.7	1.8	2.9
Initial rate, STB/D	1,500	800	900	1,200

Fig. 2.10—Matrix showing payoffs of each alternative vs. each objective.

if the NPV is extremely important to you, but all the alternatives have essentially the same NPV, it should be removed from your list of objectives, because it no longer helps to distinguish the alternatives. Likewise, remove any alternatives that do not meet a "must have" criterion or constraint (e.g., a house must have at least three bedrooms, the project must meet minimum environmental and safety standards), *and* remove the associated objective. Second, when using a constructed scale or making subjective judgments on a natural scale, compare all alternatives against a single objective rather than taking one alternative and determining its score for each objective. That is, work across the rows of the payoff matrix rather than down its columns.

If all the payoffs are numeric values, we have a further possibility for simplifying the problem: We can inspect the payoff matrix to identify and eliminate any alternatives *dominated* by others. One alternative is said to dominate another if it has higher value on some objectives and is no worse on the remaining objectives. All dominated alternatives should be removed from the analysis. An alternative may also be removed because it is *practically dominated*, which means that although it may perform slightly better on some objectives, it is not enough to make up for clearly superior performance by the dominating alternative on other objectives. If any alternative has been removed through being dominated, check your matrix again in case the performance of the remaining alternatives is identical (or practically so) on one or more objectives, which can then be removed because they no longer help to choose among the alternatives.

Consider the payoff matrix in **Fig. 2.11,** which relates to a decision to choose a logging contractor. (Note: Higher scores on the cost, safety, and equipment age objectives are *less* desirable.) It can be seen that Contractor B performs better on every objective compared to Contractor D. Because D is dominated, it should be removed. Although this case is the only case of true dominance in the table, close inspection shows that C dominates A on all objectives except cost. The decision maker decides that C has significantly superior performance on four objectives and outweighs its relatively small extra cost (especially in percentage terms); therefore, he or she deems that practical dominance has occurred, and also removes A from the set of alternatives, which leaves only B and C. Both B and C score the same on the safety objective; therefore, it can be removed.

If the payoffs for an objective are not expressed in numeric form, we can do one of two things to make them so: either assign a rank to each alternative or give it a constructed-scale score (see the "Define Attribute Scales" portion of Section 2.5.2).

		Contractor			
		A	B	C	D
Objective Attributes	Average cost, USD thousand/job	133	136	142	137
	Reputation, 0–5 scale	1	2	5	0
	Safety, lost hr/person/yr	0.05	0.01	0.01	0.02
	Average equipment age, years	5.3	2.1	1.6	4.9
	Contracting flexibility, –5 to 5 scale	0	–1	3	–4

Fig. 2.11—Payoff matrix for logging contractor decision.

A constructed scale is preferable, because it provides more precise information with which to make judgments of practical dominance. Either way, the important thing is to consider one objective at a time, and make sure you are consistent in assigning the ranks or scores to the alternatives. Dominance is an important concept in decision making and is discussed again in Section 2.7.1 and Section 5.5.1.

At this point, the payoffs can be thought of as *scores*—how well each alternative scored on an attribute scale. We now have to address two problems. First, how can our preference for different levels of achievement be incorporated into a single-attribute scale? For example, a job-enjoyment score of 6 may not be twice as desirable as a score of 3. Second, how can we combine payoffs measured on one scale with those of another? For example, barrels per day (B/D) and dollars.

Surprisingly, the first problem applies even to monetary objectives. Suppose that you are completely broke, and someone offers you USD 100. You can now feed yourself for a few days. On the other hand, if you are a multimillionaire, you may not appreciate that extra USD 100 quite so much. The reason for your difference in attitude is because in each case, the USD 100 has a different value to you because of its consequences. Thus, money is not necessarily its own measure of value!

Converting Scores to Values. The two problems identified previously can be easily overcome by using *value functions*, which transform attribute *scores* to *values* on a common scale, usually 0 to 1 or 0 to 100 (see **Fig. 2.12**). This transformation to a *common scale* enables the performances of an alternative on multiple objectives to be combined. For example, an NPV score of USD 500 million transforms to a value of 40, and a safety score of 2 units converts to a value of 70. (The next section discusses how the values should be combined.)

The value function for NPV is a straight line (linear), which in this case means that a given increment in NPV is equally preferred irrespective of absolute value—USD 100 million NPV is worth 20 value units. On the other hand, the safety value function is not linear, which means that higher scores become progressively less valuable. For example, scores below 2 may be related to loss of life; whereas, higher scores indicate levels of injury or lost time.

A linear value function is often assumed and easily defined using the range between the minimum and maximum scores of the various alternatives. For the previous example, the lowest and highest NPVs are USD 300 million and USD 800 million, respectively. There needs to be clarity about whether increasing levels on the attribute

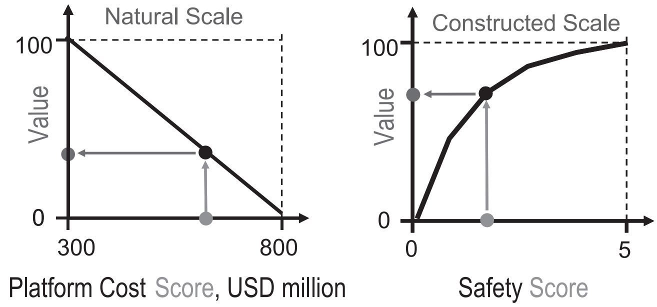

Fig. 2.12—Natural and constructed value functions.

scale increase or decrease value. For example, the score of 1 for the "environmental impact" scale in the "Define Attribute Scales" portion of Section 2.5.2 should have a value of 100, and the score of 5 should have a value of 0 (i.e., the line should slope downward).

The transformation from scores to values also offers an opportunity to further simplify the problem, if this has not already been done, by identifying any dominated alternatives, which should be removed from consideration. Having done so, the matrix should again be checked to see if there are now any objectives for which the performance of the remaining alternatives is identical (or practically so) and those objectives removed.

Utility Theory

When dealing with uncertainty, our preferences can be influenced by our attitude toward risk. We may have a preference for guaranteed outcomes over risky outcomes. For example, we may prefer a sure USD 1 million over a 50/50 chance of receiving either nothing or USD 3 million, despite the second option having a greater expected value of USD 1.5 million. Whenever any nonlinearity in the value function is caused by the adoption of some risk attitude (usually, more risky is less preferable), it is known as a *utility* function rather than a value function. Utility functions are part of utility theory—a theory of preference that takes into account both risk attitudes and values for incremental returns. In the case of multiple attributes, it is sometimes known as multi-attribute utility theory (MAUT).

It is beyond the scope of this book to discuss the full utility theory, but in the context of a company, it is only appropriate to account for risk attitude when possible outcomes of the decision have severe negative implications for the company as a whole. That is, the appropriate risk attitude is of the owner, not necessarily of the decision maker who may be driven by motives; and therefore objectives not aligned with the owner. The reader is referred to Clemen and Reilly (2001) or McNamee and Celona (2005) for an introduction to how to develop utility functions for such cases, and to Keeney and Raiffa (1993) for a more comprehensive treatment. Grayson (1960) was the first to discuss utility functions for oil and gas decision making. As discussed in Section 3.6.3, the appropriate decision criterion for any decision maker is the expected utility (EU). However, in many business contexts, the expected value (EV) is a close enough approximation to the EU [or, rather, to the certain equivalent (CE), which is the dollar value corresponding to the EU] to be used as the decision criterion.

2.6.2 Step 5—Applying Weights. This step addresses the second of the three problems associated with having multiple objectives, listed at the end of the "Multiple Objectives" portion of Section 2.5.2. Namely, the decision maker may have different levels of preference or importance for achievement of one objective over another. For example, maximizing NPV may be considered twice as important as maximizing next year's production rate. *Preference*, in this context, is used to describe the relative desirability *between* different objectives and not our preference for the incremental returns (or risks) of the various possible outcomes *within* a single objective (attribute), which was discussed in the previous step.

The solution to this problem is simply to apply relative weights to each objective. However, the weights must be assigned with care. A naïve, *direct-weighting* approach is as follows:

1. Subjectively rank the importance of the objectives.
2. Assign each a score on a scale of, for example, 0 to 100.
3. Sum all the scores.
4. Normalize their sum to 1.

This direct weighting approach is illustrated in the following example:

Objective	Rank	Weight	Normalized
Maximize safety, score	1	100	0.40
Maximize NPV, USD million	2	90	0.36
Minimize initial rate, million B/D	3	40	0.16
Maximize Reserves, million STB	4	20	0.08
		Sum = 250	1.00

However, this approach can cause a problem, because it ignores the payoffs of the alternatives. Consider NPV, which is ranked second-most important. What if the expected scores of the alternatives were remarkably similar, say, USD 401 million, USD 398 million, USD 405 million, and USD 403 million? The NPV is no longer a powerful discriminator of the relative merits of the four alternatives. The problem is caused by forgetting the ultimate purpose of the objectives at this stage in the analysis, leading to an error in defining what is meant by "important." The objectives should be ranked according to their importance in *distinguishing between alternatives*, not some absolute measure of importance (as they were when being used to help identify good alternatives). In the extreme, if the scores of all alternatives were the same, then the weight should be set to 0, which has the same effect as removing the objective altogether.

In practice, the problem can be overcome by using *swing weighting*, which takes into account the relative magnitudes of the payoffs. The objectives are first ranked by considering two hypothetical alternatives: one consisting of the worst possible payoffs on all objectives (in terms of score, not value), and one consisting of the best possible payoffs. See **Fig. 2.13** for an example.

The objective with the best score that represents the greatest percentage gain over its worst score is given the highest rank, and the methodology is repeated for the remaining objectives until all are ranked. As can be seen, maximizing reserves is now ranked as the most important. Steps 2 to 4 of the direct-weighting procedure are then followed to determine weights.

Although the weights can be considered part of the value tree, the preceding problem shows why they are not assigned in Step 2, but are deferred until all the alternatives are identified and their payoffs are determined.

Having determined the swing weights, the payoff matrix can be inspected for practical dominance, this time in the light of the new weights (actual dominance does not

	Actual Alternatives					Hypothetical Alternatives		Swing Rank
Attributes	A	B	C	D	E	Worst	Best	Rank
Initial rate, thousand bbl/D	30	20	25	40	20	20	40	2
Reserves, million STB	100	350	180	290	400	100	400	1
NPV, USD million	110	115	100	120	110	100	120	4
Safety, score	4	3	5	3	5	3	5	3

Fig. 2.13—Illustration of swing weighting.

Objectives				Location Values				
Name	Swing Rank	Weights		A	B	C	D	E
		Abs.	Norm.					
Safety, 0–10 scale	3	60	0.18	40	10	0	100	80
NPV, USD million	1	100	0.29	70	0	100	30	60
IRR, %	4	40	0.12	100	40	90	0	30
Reserves added, million STB	5	30	0.09	90	80	100	70	0
First year production, million STB	2	90	0.26	60	100	50	0	40
Risk, probable NPV<USD 0	6	20	0.06	40	80	0	100	90
	Total	340	1.00	65.6	44.6	61.8	39.0	51.2

Fig. 2.14—Typical spreadsheet record and evaluation of Steps 2 to 6.

change, because the payoff values have not changed). If any alternatives are selected for removal, then check if any objectives can also be removed (if all remaining alternatives now perform the same on a given objective).

2.6.3 Step 6—Determining the Best Alternative. The final part of the evaluation and modeling phase is to combine the scores on each objective to determine an overall value for each alternative.

This determination of an overall value is achieved by calculating the weighted sum of each column in the value payoff matrix. That is, the weighted overall value, V_j, is computed for each of the N_j alternatives over the N_i objectives:

$$V_j = \sum_{i=1}^{N_i} w_i v_{ij}, \qquad (2.1)$$

where w_i is the weight of the ith objective, and v_{ij} is the payoff of the jth alternative for the ith objective. Because of uncertainty, the payoffs should be *expected values* (in the probabilistic sense, as described in Chapter 3), typically resulting from a decision-tree analysis or Monte Carlo simulation. **Fig. 2.14** illustrates, in the format of Fig. 2.8, Steps 2 through 6 for a choice among five locations for an infill well.

The alternatives are then ranked according to their scores. The first-ranked alternative (A, in this case) is the one logically consistent with maximizing the value of the decision, given:

- The alternatives identified
- The values and objectives and their weights
- The forecasted payoffs based on the information we have

In other words, *we have employed a methodology that yields a good- or high-quality, decision*, as defined in Chapter 1 and in Section 2.4. As mentioned previously, this methodology has its theoretical underpinning in decision science.

In theory, if we are sure of our preference for outcomes, risks, relative importance of objectives, etc., then we should choose the top-ranked alternative. However, it may not necessarily be the preferred choice, particularly when the following occurs:

- We are not absolutely sure of the weights for the various objectives.
- Some objectives are conflicting (see next section).
- There is a small difference among the overall scores of several alternatives, but they satisfy different objectives significantly.

Making comparisons in a matrix of numbers is seldom the easiest way for people to analyze the information or to present it to decision makers. One option is to present the payoff table in the form of a *radar chart* (see **Fig. 2.15**). Each "spoke" of the chart represents one of the attributes. The 0 is generally at the center of the chart, and 100 (or 1) is on the outer rim. (However, in Fig. 2.15, we placed the 0 value one "ring" out from the center, which facilitates comparing the alternatives when their value is 0.) Each alternative is plotted using a line to join its values on each attribute. Either the direct or weighted values can be plotted, which makes it much easier to examine the alternatives and discern which aspects contribute to, or detract from, the overall value. If the line for one alternative lies entirely inside the line of another, then the latter dominates the former and should be removed. (Our example does not show any cases of this occurrence.)

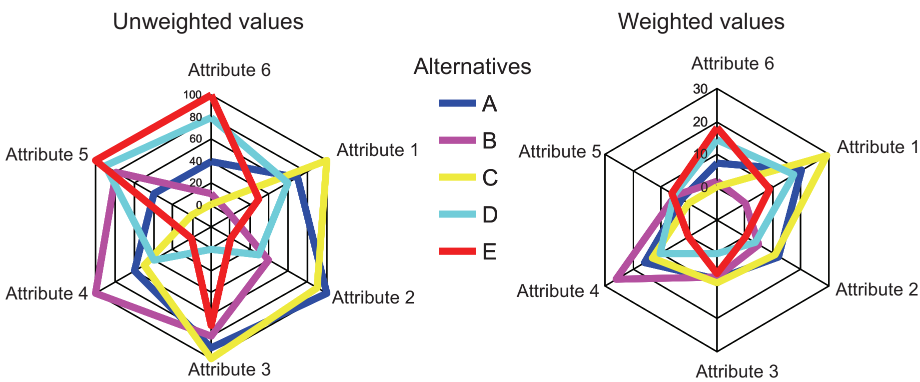

Fig. 2.15—Radar or spider plots showing performance of the alternatives on each attribute.

However, things are not so simple in the case of numerous alternatives, such as deciding the percentage allocation of an annual budget among an infill well program, a workover program, and a sidetrack program. Because the percentage split is a continuous variable, there is an infinite number of ways to split the budget. This type of problem requires a formal optimization approach, which is outside the scope of this book.

2.6.4 Summary and Remarks. The modeling and evaluation phase uses the results of technical modeling and analysis (including technical uncertainty analysis) in the decision-making methodology. It is also the phase in which the main decision-modeling activity takes place, through the use of tools (e.g., decision trees and Monte Carlo simulation) that are discussed in subsequent chapters.

It is easy, particularly for people who are quantitative, to lose sight of the overall objective of attaining clarity of action and instead become absorbed in the calculations. The real drivers of value are precision in definitions, fit-for-purpose modeling, clear objectives, creative thinking, objective assessment of information, and logical analysis—followed up by good record keeping. Extensive discussion may be required to ensure that everyone has at least a common understanding of, if not agreement with, each of the previously discussed elements.

Disagreements about which alternative should be chosen often focus on people's differing opinions about the likely outcomes of the uncertain payoffs. However, the disagreement often concerns the objectives, their weights, and the value functions. Following the previous procedure at least reveals these sources of disagreement, if not helping to resolve them. Barring a convincing argument of faulty analysis, persistent support in favor of an alternative not ranked highly may be an indication of a hidden agenda.

The decision-analysis part of this phase is likely to account for only a small fraction of the elapsed time—the majority being spent on the technical, economic, and commercial analyses required to develop the payoff matrix. If the latter information is readily available, the elapsed time is greatly shortened. Clearly, the amount of time depends on the scope, or size, of the decision, and the availability of information. As before, some iteration is likely required between the various sub-steps as insight is gradually gained.

As with Phase 1, if you are participating in a decision in which you are not the decision maker, we recommend that the analysis-to-date be reviewed with the decision maker(s). Then, formal approval should be sought from the decision maker(s) for the adequacy of the evaluation of the payoffs, value functions, and weighting of the objectives. We also strongly recommend that the source of the payoff data (e.g., from technical studies) be recorded along with any reasoning behind the weighting of the objectives and choice of value functions.

2.7 Phase 3: Assessing and Deciding

The final phase of our proposed methodology consists of two steps. The first step considers the impacts of any competing objectives and the desirability of making tradeoffs between them. The second step conducts an analysis of the sensitivity of the decision to input variables and parameters, such as objective weights, probabilities, or payoffs.

2.7.1 Step 7—Tradeoffs. Section 2.5.2 (Objective Setting) and the "Multiple Objectives" discussion within that section noted that conflicting objectives can make decisions hard. For example, maximizing a short-term production rate may decrease reserves, increasing safety may decrease profit by increasing cost, or enjoying a job may have to be traded off against salary. A fundamental economic principle is that increasing returns come at the expense of increasing risks, in which *risk* is used in its economics sense, equivalent to what we term *uncertainty.* This tradeoff between risk and return is a characteristic of portfolio-selection decisions.

This difficulty can be addressed by first categorizing the objectives into two classes, using natural divisions related to the tradeoffs that have to be made (e.g., costs and benefits, risk and returns). Overall weighted scores are then calculated for each subset, in a similar fashion to Section 2.6.3 . For example, using C to indicate costs and B to indicate benefits, the overall weighted values for the costs and benefits, respectively, of alternative j are given by the following:

$$V_j^C = \sum_{i=1}^{N_C} w_i v_{ij} \qquad V_j^B = \sum_{i=1}^{N_B} w_i v_{ij}, \quad \text{(2.2)}$$

where N_C is the number of objectives classified as costs, and N_B is the number classified as benefits. The next step is cross-plot the weighted cost/benefit pairs for each alternative as shown in **Fig. 2.16**, in which higher cost *values* represent lower actual costs (scores).

This plot is interpreted and used through several steps. First, discard all dominated alternatives. Consider alternative A, shown by the yellow triangle. With respect to alternative B (the red circle), A has both lower cost value (higher actual costs) and lower benefit value. Because B is superior to A on both measures it dominates A, so A should be discarded. All other pairings can be evaluated similarly to identify the set of non-dominated alternatives—in this case, B, D, F, and G. These non-dominated alternatives are viable alternatives, and are termed the *efficient frontier.* The next step is to start from either the upper left or lower right, and move along the efficient frontier,

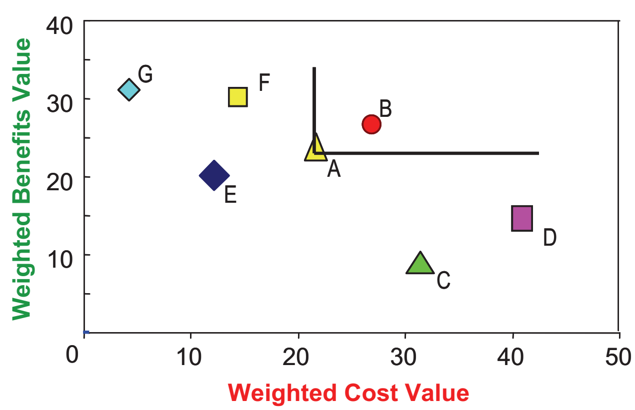

Fig. 2.16—Assessing tradeoffs between conflicting objectives.

each time asking, “Am I willing to accept this change?” In other words, am I willing to trade off the change in benefit for the change in cost? For example, comparing Alternative G with F, we ask, “Is a decrease of approximately 2 value-units of benefit worth an increase of approximately 10 value-units of cost?” If the answer is yes, we discard G, and then make the same comparison between F and B, and so on, until we are no longer willing to make the tradeoff. The last alternative for which we are willing to make the tradeoff is our final choice.

The previous example used benefits and costs in a loose sense to indicate things that were *desirable* and *undesirable*, respectively. If the costs are simply real dollar costs rather than an amalgamation of attributes that contribute to cost, then we can use those actual cost *scores* and thus be able to assess the tradeoff question in terms of real costs.

Portfolio decision making is another application in which the efficient frontier is used to make tradeoffs. In this context, each alternative is a possible portfolio of investments and the desirable quantity is the average NPV of the portfolio, which is to be traded off against the undesirable risk of the portfolio, in which risk is often defined as the standard deviation (or variance) in the NPV.

The previous discussion of dominance assumed that the scores are either deterministic quantities or the average values of uncertain variables. However, defining dominance in the latter case is not quite so straightforward, because there are many possible outcomes of the uncertain variable. In this case, we can use *stochastic* (or probabilistic) *dominance*, discussed in Section 5.5.1.

Even Swaps. In this section, we briefly review an alternative method, *even swaps*, for making tradeoffs. A fuller discussion can be found in Hammond et al. (1998). This approach starts at the point of having ensured that all entries in the payoff matrix are numeric values, any descriptive ones having been converted to numbers through a constructed attribute scale in accordance with the “Define Attribute Scales” portion of Section 2.5.2.

The basic idea is to create dominance, when there was none before, by making equal- value tradeoffs. To illustrate, we return to the example shown in Fig. 2.11. Alternatives A and D are removed through dominance, and the “Safety” objective is removed, because the remaining alternatives, B and C, had the same score. The decision problem is now as shown on the “Before Swap” part of **Fig. 2.17.**

It can be seen that Alternative B is dominated by Alternative C on all the remaining objectives except cost, which is USD 6,000 less for Contractor B. The decision maker

	Before Swap		After Swap	
Objective Attributes	B	C	B	C
Average cost, USD thousand/job	136	142	142	142
Reputation, 0–5 scale	2	5	2	
Average equipment age, years	2.1	1.6	2.1	1.6
Contracting flexibility, –5 to 5 scale	–1	3	2	

Fig. 2.17—Logging contractor decision problem after removing dominated alternatives and irrelevant objectives.

looks for an opportunity to tradeoff this USD 6,000 against superior performance on another objective. "Contracting Flexibility" looks like a natural possibility, particularly because the decision maker does not attribute much weight to this objective. The decision maker judges that the USD 6,000 cost advantage of Alternative B provides the same value as, or can be compensated for by, an increase worth three units of "Contracting Flexibility." Having made the swap, the cost objective becomes irrelevant and Alternative C dominates the remaining objectives. It is the best choice. In this example, one swap was sufficient to reach a decision. However, most problems are more complex and require repeated application of even swaps to successively simplify the problem by creating dominance or removing objectives.

The goal of even swaps (i.e., finding the dominant alternative) is the same as using value functions in combination with swing weights. However, because the process is implemented through sequential one-at-a-time comparisons, it is important to ensure consistency and to be aware of the opportunity it presents for manipulating the tradeoffs to now be dominated by an implicitly preferred alternative (which is more difficult to do with the swing-weighting/value-function approach).

2.7.2 Step 8—Sensitivity Analysis. The final step in our proposed methodology for making high-quality decisions, and thus our best hope for good outcomes, is to determine how sensitive the decision metrics (payoffs) are to changes in our estimates of inputs or assumptions, particularly with respect to uncertain quantities and variables over which we have choice (e.g., well numbers).

The quantitative input to the methodology can be divided into three main categories. The first category is the subjective assignments of how we perceive value. For example, we may not be able to unambiguously assign weights to objectives or to specify value functions. The second category is related to the information used to calculate the payoffs (e.g., porosity, oil price, seismic velocity, and gas/oil ratio). Much of this information is uncertain, quantified by objective measurement or subjective assessment. The third category relates to parameters whose values we can choose (e.g., number of wells, processing capacity, or pipeline diameter).

A key question is, "How accurately do we need to know these inputs?" This question can be answered by assessing to what extent the final decision is *sensitive* to changes in the inputs. If the decision is fairly insensitive to a particular input, then it does not need to be quantified more precisely. On the other hand, if the decision is sensitive to an input, then the following can be considered:

- If it is of the value type, we want to think more deeply about what matters to us.
- If it is of the informational type, we may want to assess it more accurately, try to reduce the uncertainty, or design plans to deal with its consequences. (Chapter 5 describes two powerful approaches to managing the impacts of key uncertainties, VOI and VOF.)
- If it is of the choice type, we may want to find the value that optimizes the overall value of the decision.

There are several ways of performing sensitivity analysis. The remainder of this section describes two common approaches and illustrates their application to the three quantity types described previously. Both approaches are based on the principle of changing the inputs one at a time and observing the resulting impacts on the output variables, which requires access to a quantitative model that calculates values of the payoffs from the input variables. The main differences in the methods is in how the results are displayed and in whether we are evaluating the effects of a single input on multiple payoffs or vice versa.

Tornado Charts—Single Objective, Multiple Uncertainties. The first approach is used to assess the sensitivity of a single-output variable to changes in multiple inputs. It can be used to help identify two decision-driver types: uncertainty drivers and value levers.

- **Uncertainty Drivers.** These variables are uncertain model-input variables that have the biggest impact on the payoffs. Identifying these variables is useful for two main reasons. First, it is a quick technique that enables screening multiple uncertainties at an early stage to determine which one(s) should be included in decision-tree analysis or be more fully evaluated using Monte Carlo simulation. Second, it may provide compelling evidence to direct spending on further data collection or allocation of personnel to technical analysis.
- **Value Levers.** Value levers are model parameters whose values the team can choose and that have the biggest impact on the payoffs. Identifying these variables is useful because they provide insight into the question of which ones the team should concentrate on in either an ad hoc or a more formal approach to optimizing the value of the decision.

The general procedure includes several steps. First, select the input variables and the payoff for which the sensitivity analysis is required. Second, one at a time, change the input variables by plus and minus a given amount, and record the value of the payoff for each change. Changes of plus and minus 10% are often used. Although this change reflects the sensitivity of the payoff to the input, it can be misleading in terms of identifying which variables are the most important input variables, unless their degrees of uncertainty are similar. A better scheme is to derive the changes from an assessment of the probability distributions of the input variables. The input variables are then ranked in order of decreasing impact on the payoff, the impact being calculated as the absolute value difference in payoff for the plus/minus changes. Using the initial (before sensitivity analysis) value of the payoff as a center point, the changes in its value are plotted on a bar chart in descending order of impact, as shown in **Fig. 2.18a,** which illustrates the approach applied to a field development decision with NPV as the payoff. The typical tornado shape of these bar charts accounts for their name.

Fig. 2.18a indicates the NPV of the model is approximately USD 550 million, and it is most sensitive to changes in the reservoir area, followed by porosity, and least sensitive to platform cost. The former variables are candidates for a more rigorous assessment of their uncertainty, such as inclusion in decision-tree analysis; any further data collection or analysis should focus on reducing their uncertainty or managing its impacts.

Fig. 2.18b shows the same analysis type applied to the main choice variables. The NPV is shown to be most sensitive to the platform size, number of wells, and facility capacity. These variables should be pursued to optimize the overall value of the decision.

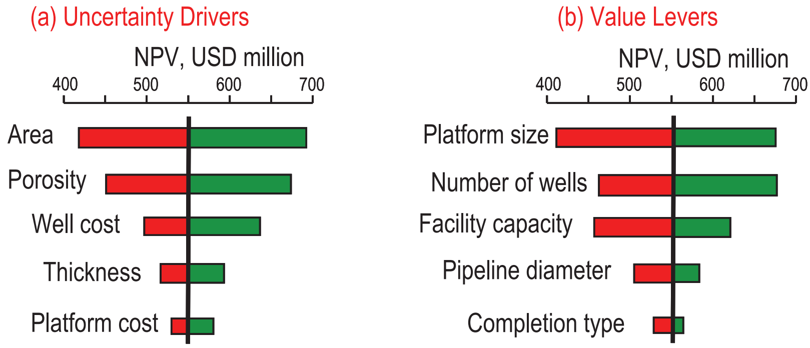

Fig. 2.18—Tornado sensitivity plots to identify main uncertainty drivers and value levers.

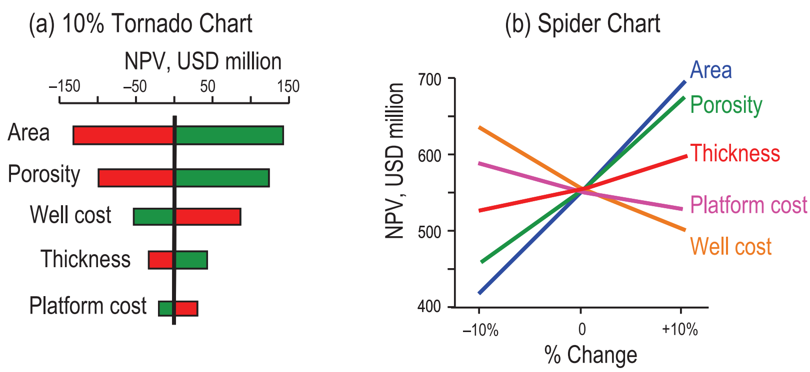

Fig. 2.19—(a) Tornado chart showing direction of sensitivities, (b) spider chart.

Interpreting these plots necessitates being aware of the correct directional variations of the sensitivities. For example, as area increases, the NPV increases. However, as the well cost increases, the NPV *decreases* (in this example, a 10% increase in well cost induces a decrease of approximately USD 50 million). The effect of any aggregation or splittingof the sensitivity variables must also be accounted for. In the previous example, it would have been possible to choose aggregated OOIP as a variable, rather than its components (i.e., area, thickness, etc.).

Several variations are possible to the standard tornado chart. One is to subtract the initial value of the payoff to make the center line zero, thereby making it easier to see the actual dollar amounts of the sensitivity. Another is to color the bars to show the direction of the sensitivity. Both these variations are illustrated in **Fig. 2.19a.** An alternative way of displaying the information is as a *spider chart*, as shown in Fig. 2.19b. The steeper the line, the more sensitive the payoff is to the variable. The slopes of the lines in the spider chart need be neither symmetric about the zero point nor linear. Different slopes indicate that the sensitivity is different for positive and negative changes in a variable.

Single Uncertainty, Multiple Objectives. The second approach assesses the effect of changing a single-input variable on multiple outputs. It works well for investigating the sensitivity of the decision to the choice of weights assigned to the objectives. The main idea is to take one (normalized) weight at a time and, while holding the others constant, vary it between 0 and 1 in a number of discrete steps, observing the impact on the overall weighted values. Because the normalized weights must sum to 1, the other weights must be prorated for each value of the weight being varied. Normally, one starts with the objective that has the highest weight, and so on. Suppose Objective 4 has the highest weight, such as 0.18.

Fig. 2.20 shows the result of performing the previous procedure. The overall weighted score of each alternative is plotted at each value of the weight, and the points are joined to form one line for each alternative. At Objective 4's current weight, 0.18, Alternative A is shown to be the best choice. Moreover, Alternative A remains the best choice for any weight between approximately 0.1 and 0.4. Below 0.1, Alternative C becomes the best choice, and above 0.4, Alternative D is the best choice. Above a weight of approximately 0.47, Alternative E becomes the best choice, which tells us that as long as we are confident that the weight of Objective 4 lies in the range 0.1 to 0.4, the decision is robust.

Multi-Variable Sensitivity Analysis. The previous techniques are forms of *deterministic sensitivity analysis*, because the changes in the input variables are chosen arbitrarily, rather than being driven by probability distributions of the uncertain variables. They are useful for screening which variables should be modeled in more detail, but do not provide a true measure of the dependency of payoff uncertainty on input-variable uncertainty. A more sophisticated version of tornado chart sensitivity analysis, known as *probabilistic sensitivity analysis*, is described in the Monte Carlo simulation section in Chapter 4. This type of analysis enables all variables to change together and for those changes to be determined by the probability distributions of the respective variables. Consequently, it can provide an absolute measure of the extent to which uncertainty in the input variables drives uncertainty in the payoffs.

Finally, we can investigate how sensitive the value of the decision is to either the reduction of uncertainty by acquiring more data or conducting further analysis, or to the implementation of flexibility to respond to the outcomes of uncertain events. The

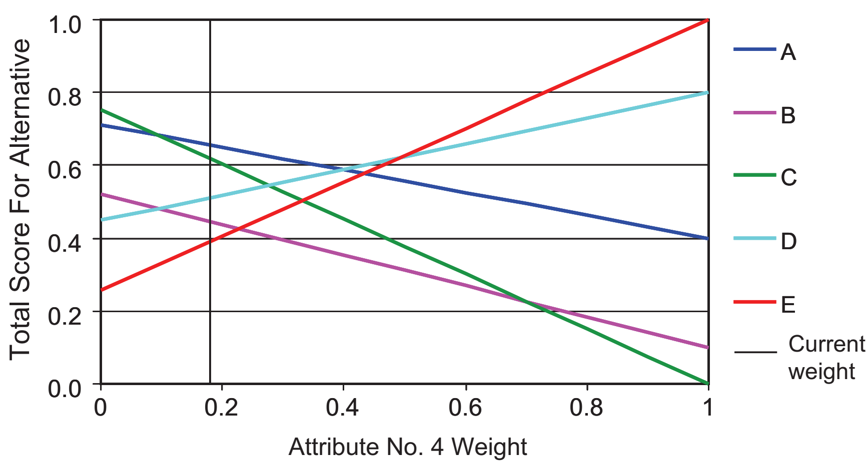

Fig. 2.20—Sensitivity of decision alternative scores to Objective 4 weight.

description and implementation of these two types of sensitivity analysis are covered in Chapter 6 because they require an understanding of probability theory and decision trees, which are covered in Chapters 3 and 5, respectively.

2.7.3 Summary and Remarks. The final phase of our recommended decision-making methodology is designed primarily to address two of the factors that make decisions hard—conflicting objectives and uncertainty (in a loose sense of the word) around the values of the different types of input that determine the payoffs.

Conflicts between objectives can be resolved by considering the value of making tradeoffs between them. As part of this procedure, the number of alternatives worth considering can be reduced by excluding all alternatives for which another alternative scores at least as highly on all objectives.

Sensitivity analysis is beneficial, because it identifies the following:

- Variables or parameters on which it is not worth expending further effort to resolve their values, because they are not material to making the decision
- Key uncertainty drivers, over which we have no control, other than to reduce the uncertainty by collecting more data or performing more analysis, or to develop plans to mitigate risks or capture opportunities that arise from them
- Key value levers, which can be chosen to optimize the value of the decision
- General insight into the behavior of the decision situation

Together, these benefits can create a more decision-driven atmosphere through each team member's knowing the relevance (or irrelevance) of their contribution, thereby maximizing the efficiency of human and financial resources. We have found that technical specialists are willing to accept a level of analysis that is not all-encompassing, when it can be demonstrated to be adequate for the purpose for which it is intended. Without this evidence, there is a natural tendency to do the best job possible, often leading to a focus on precision rather than overall accuracy of the analysis.

Conducting and interpreting a sensitivity analysis requires delving beyond the simple tornado style sensitivity charts to investigate the multidimensional nature of the sensitivities (i.e., a key driver may be important only for particular combinations of other variables).

The analysis-to-date should be reviewed with the decision maker(s), whose formal approval should be sought and recorded for the adequacy of the evaluation of the tradeoffs and recommendations for further data collection or analysis. The final decision, of course, lies with the decision maker.

2.8 Assessing Decision Quality

The previous methodology is designed to deliver good decisions, where a good decision is defined as one that is logically consistent with maximizing the value of the decision, given the following:

- The alternatives that have been created or identified
- The decision-maker's objectives and associated weights
- The forecast payoffs based on the information we have
- The decision-maker's preferences for payoffs, as specified by the value functions

But how can we assess the quality of the decision, given that the outcome is not a reliable indicator? We present a framework based on McNamee and Celona (2005) and Matheson and Matheson (1998). In addition to assessing the quality of a current decision, the framework can be used either as a means of auditing previous decisions or as an introduction to or summary of the actual methodology.

2.8.1 The Six Dimensions of High-Quality Decision Making. Matheson and Matheson (1998) surveyed a large number of decision makers and combined their responses with the thinking of academics to develop a framework that evaluates the quality of a decision along the six dimensions shown in **Fig. 2.21.**

As shown in Fig. 2.21, the six dimensions form a chain-of-decision quality and broadly reflect the main elements of the methodology described previously.

1. Helpful Frame. The starting point is to clearly identify the decision to be made and how accurately it needs to be assessed. A helpful frame clarifies the situation to be solved. The importance of this step cannot be underestimated. Getting a great answer to a poorly framed problem or opportunity is useless. As engineers and geoscientists, we tend to immediately employ models (i.e., simulation tools, spreadsheets, geological modeling and analysis, etc.) when facing a new decision situation. Expert decision makers, however, know that they must consciously identify what needs to be decided. Too often, pressed for time and an immediate answer, inexperienced decision makers plunge into gathering information or building a quantitative model without stopping to ask questions, such as the following:

- What is being decided?
- What is not being decided?

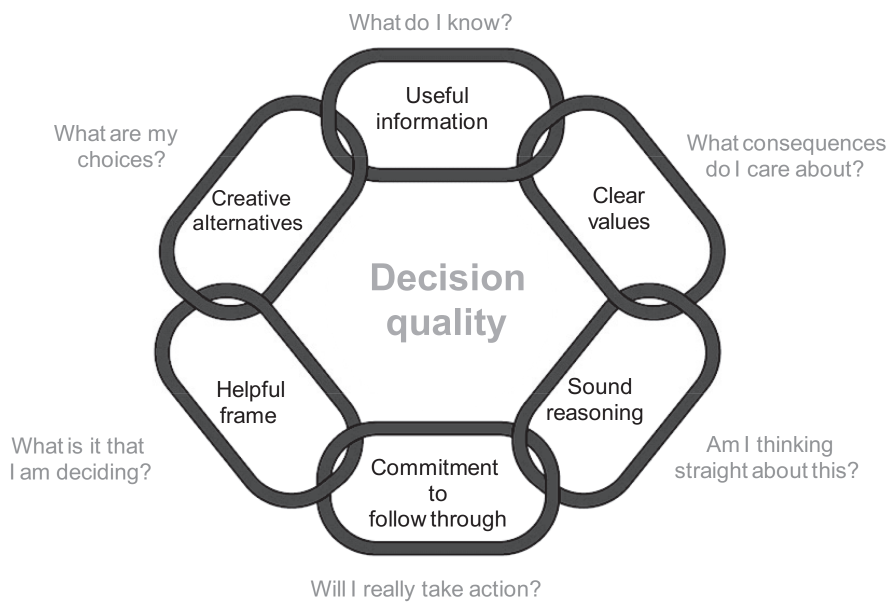

Fig. 2.21—The decision-quality chain.

- What will we take as given?
- Are the assumptions clearly specified?

No matter how little time is available, one should never omit asking the framing-type questions. If you do not ask well, you may waste more time than you "save," because you risk solving the wrong problem.

2. Creative Alternatives. The lack of creative and flexible alternatives is one of the main reasons companies have difficulty in achieving high-quality decisions. This dimension can be illustrated by asking questions such as the following:

- What are my choices?
- Are the alternatives doable?
- Do the alternatives solve the problem?
- Was a broad range of alternatives considered?

This dimension requires the team to stretch its imagination and be creative. Each alternative identified should be logically consistent and feasible. Any decision can only be as good as the best alternative identified, and if there are no alternatives, there is no decision.

3. Useful Information. This dimension emphasizes the need to bring reliable and relevant information to bear on the decisions. It can be illustrated by asking the following questions:

- What do we know?
- Did we obtain information on the important things?
- Was the information unbiased?
- How accurate have we been in the past with a similar assessment?
- What information would we gather, given more time/money/resources?

Companies and individuals are often good at including what they know in the analysis. However, a particularly dangerous tendency is aptly illustrated by the following quote:

> *It ain't so much the things we don't know that get us in trouble. It's the things we know that just ain't so.*
>
> —Artemus Ward

The key to quality in this dimension is information about what is not known (i.e., the limits of our knowledge). Too many decisions are based on wrong or incomplete information. Consciously considering the information needs and gathering useful information before acting are essential to good decision making.

4. Clear Values. As discussed previously, an essential component to good decision making is to clearly define and articulate the criteria for measuring the value of alternatives and how the company makes tradeoffs between them. For most E&P companies, the key criterion is some combination of the NPV, cash flow, production, and reserves replacement. Good questions to ask include the following:

- What consequences do we care about?
- What tradeoffs did we make?
- Have we been able to accurately measure these values in the past?

Tradeoffs are often necessary, and clarity in how the criteria are ranked is essential.

A commonly expressed *value metric* in E&P is reduced uncertainty or increased confidence. As we subsequently discuss, these metrics have no economic value by themselves. Another danger is to ignore intangible decision metrics, such as *corporate reputation* or *safety*.

5. Sound Reasoning. Reasoning is how we combine our alternatives, information, and values to arrive at a decision. It is our answer to: "We are choosing this alternative because…." This dimension requires bringing together the inputs of the previous dimensions to determine which alternative creates the most value. In most cases, the decision situation is too complex to rely on intuition and requires a model. This dimension can be illustrated by asking the question: "Am I thinking straight about this?"

It is not uncommon in the E&P industry to develop models too cumbersome to deliver the required clarity and transparency. The common procedure of developing a "base case" sometimes results in a detailed and complex deterministic model that ignores not only the uncertainty but often also the key dependencies. Its precision may lead to a false belief in its accuracy and relevance, as discussed in Chapter 7.

The goal of the evaluation is to develop a clear, transparent, and understandable recommendation that maximizes the values of the decision maker.

6. Commitment To Follow Through. This dimension moves decisions to implementation, which is not trivial. The best decision is useless if the organization does not implement it. If we are only halfhearted about our commitment, our follow-through is usually less intense and may not achieve the best results. This dimension can be illustrated by asking the following questions:

- Is the recommendation appropriate and feasible?
- How are we going to communicate the decision?
- Can the organization support the decision?
- Is there an implementation plan?

Successful follow through requires resources, such as time, effort, money, or help from others. It also requires being prepared to overcome obstacles.

2.8.2 The Strength of the Whole. Any decision is no stronger than its weakest link. If, for example, a decision is good in all elements except the frame, it is still of low quality. To use decision quality as a metric, Matheson and Matheson (1998) recommended that the chain be converted into a spider diagram, as shown in **Fig. 2.22.** In this diagram, 0% quality is in the center for any of the dimensions, while 100% quality is on the perimeter. The diagram can be used to subjectively assess the decision on each dimension. A 100% rating on a dimension indicates that additional effort to improve this dimension is not worth the cost. For example, in any E&P decision situation, it is always possible to acquire more information. At some point, however, additional information either does not impact the decision or is not economical.

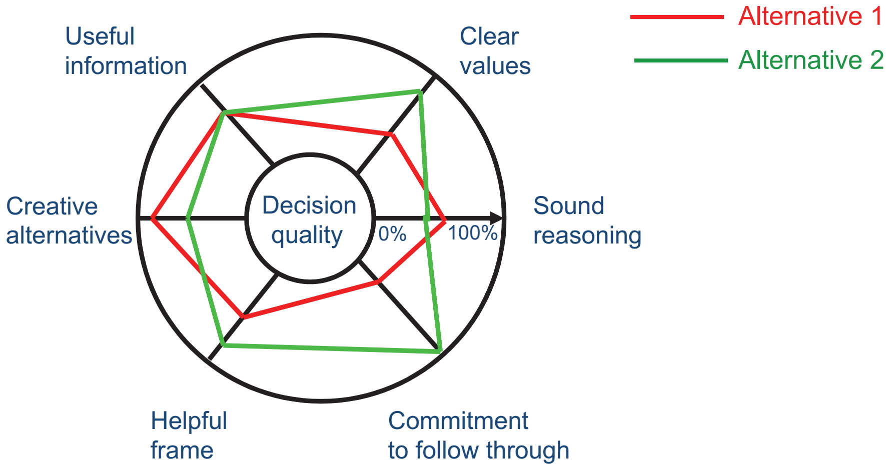

Fig. 2.22—Decision-quality spider diagram.

The spider diagram is most effectively generated by interviewing the individuals involved in a decision situation. The tool can be used to assess the decision quality during both the decision-analysis process and at postmortem. Fig. 2.22 illustrates two example project decisions. Although the red decision has the higher quality in the "Creative Alternatives" and "Sound Reasoning" dimensions, the green decision dominates in the other four dimensions. The diagram also shows that the green decision's weakest dimension is "Sound Reasoning," which may suggest that more work is required to improve the underlying model.

2.9 Summary

We have presented a general, widely applicable methodology for making good decisions. A key advantage is the transparency it brings. In particular, it can help to uncover hidden agendas that are the source of unresolved differences in opinion about the best course of action. It also brings about a realistic assessment of uncertainty and therefore of the role of chance in determining the eventual outcome. Creating transparency of objectives, values, and decision criteria helps to focus the discussion on the real issues that drive the decision. It clarifies whether differences in opinion arise from how we perceive value or from the informational aspects of the decision situation. It should lead to a compelling course of action and therefore to acceptance by those having a stake in the decision or its implementation.

If you want your organization to develop a competitive advantage through improved decision making, monitoring of individual decisions, assessment of their quality, and tracking of the results, the decision-quality chain should be considered. To be effective, it needs to be accompanied by the development of a reward system that is driven by decision quality and also encourages alignment of objectives, realistic assessment of uncertainties, and appropriate attitudes toward risk.

2.10 Suggested Reading

Identifying the elements of the decision situation is the initial step in the decision-analysis approach. Ralph Keeney's book *Value-Focused Thinking* (1992) emphasizes the need to understand the decision maker's values as a prerequisite for high-quality decision making. Keeney provides a good summary in the article "Creativity in Decision Making with Value-Focused Thinking" (1994) and provides a list of the 12 most common mistakes (2002).

Several of the references listed at the end of Chapter 1 discuss the decision-analysis process [Clemen and Reilly (2001), Goodwin and Wright (2004), and McNamee and Celona (2005)]. Kirkwood (1997) also includes a discussion of the decision methodology.