■ KRISHNA S. DHIR, Feature Editor, Campbell School of Business, Berry College

Decision Analysis in One Chart

by Gregory S. Parnell, United States Military Academy at West Point

Why am I a decision analyst? I often tell students and colleagues that I use the "Willie Sutton theory of operations research." According to the legend, when Willie was finally captured after robbing many banks, he was asked, "Why do you rob banks?" His classic response was, "That's where the money is!" In most of my professional career and academic research, I have used decision analysis to inform decision makers responsible for complex resource allocation decisions involving large investments.

As a practicing decision analyst and past president of the Decision Analysis Society of INFORMS, I am frequently asked to develop a decision analysis methodology for a new application or to review a proposed methodology. As an academic and a consultant, I have learned the importance of carefully defining any discussion and using a summary chart to tell a story. In this short article, I would like to define decision analysis and describe the scope of decision analysis using one chart. Clearly this is a daunting task, and I did not stay the chart would be simple!

Figure 1 provides my view of the current scope of decision analysis, the key concepts, and the most common techniques used by practicing decision analysts. My hope is that readers can use this chart to assess their understanding of decision analysis and use the references in this article to expand their understanding of the concepts and techniques in this important and useful field.

Field of Decision Analysis

Decision analysis is an operations research technique for analyzing complex decisions with multiple (and usually conflicting) objectives and uncertainty. One of the founders of the field, Ronald Howard, first coined the name in 1964. Decision analysis uses the axioms of probability and utility theory and the philosophy of systems analysis (Howard, 1966). The first decision analysis book (Raiffa, 1968), used probability and a single objective, net present value. The first multiple objective decision analysis book was published in 1976 (Keeney & Raiffa). Decision analysts are Bayesians since we believe that probability is a personal assessment of our belief in the outcome of an event based on our state of information, and we use Bayes law to update our beliefs as we learn new information. In addition to the mathematical foundations of decision theory, decision analysts have adopted lessons from behavioral decision theory research (von Winterfeldt &. Edwards, 1986) about the heuristics and biases people use to reason with uncertain information and make decisions. Decision analysts have used behavioral decision theory research to develop effective probability, value, and utility elicitation protocols (Watson & Buede, 1987; Clemen, 1996; and Kirkwood, 1997).

Scope of Decision Analysis

In order to assess the potential use of decision analysis to meet decision challenges, we need a clear understanding of the concepts and techniques of decision analysis. Figure 1 provides one possible decision analysis framework to describe the major concepts and techniques.[1] The framework begins in the middle by identifying a Decision Opportunity. I use opportunity instead of problem to emphasize that at any time we can

Gregory S. Parnell *is a professor of systems engineering at the United States Military Academy at West Point and teaches decision and risk analysis, systems engineering, and operations research. He received his PhD from Stanford University. His research focuses on decision analysis, risk analysis, and resource allocation for defense, intelligence, homeland security, and environmental applications. He co-edited* Decision Making for Systems Engineering and Management, *Wiley Series in Systems Engineering (Wiley & Sons, 2008), and has published over 100 papers and book chapters. He is a member of the Chief Technology Officer and Information Assurance Panels of the National Security Agency Advisory Board and is a former chair of a National Research Council study on bioterrorism risk analysis. He is a senior principal with Innovative Decisions Inc., a decision and risk analysis firm, and a former principal with Toffler Associates, a strategic advisory firm. He has served as president of both the Decision Analysis Society of the Institute for Operations Research and Management Science (INFORMS), and the Military Operations Research Society (MORS). He is a fellow of the MORS and INFORMS.*

Gregory.Parnell@usma.edu

develop a decision opportunity and not only when we are faced with a decision problem. The framework is composed of dimensions, branches, and levels. The four dimensions are the decision (single and multiple alternative branches), the decision maker and stakeholder interaction (single and multiple decision maker branches), the value and time preference (two value preference and a time preference branch), and the uncertainty and risk preference (uncertainty and risk preference branches). The levels on each branch represent increasing complexity as we move away from the origin. The gray levels are not recommended. The black text lists some of the most common techniques for each dimension. In limiting the chart to one page, I have had to be selective about the techniques that I have included. The references at the end of this article and the *Decision Analysis Journal* are excellent sources of additional decision analysis concepts and techniques.[2]

The Decision Dimension

The decision dimension captures three important distinctions: the type of alternatives, the number of alternatives, and the decision level of the alternatives. The type of alternative can be an existing alternative (e.g., an existing home at a specific address) or an alternative that must be designed (a new home to be designed and constructed at some location to be determined). The second distinction is the number of alternatives. For example, most of us buy one home, but we purchase a portfolio of financial investments (including our home). The third distinction is the decision level of the alternatives. The complexity of the decision changes as the level changes from organizational decisions (what products to produce or services to provide) to organizational strategy (what mission to perform) to national policy (what strategy to achieve national objectives) to international policy (what strategy to achieve international objectives). Usually, decision complexity increases as the decision level increases. In addition, at any decision level, the complexity increases as the number of decisions and the potential for new alternative designs increases.

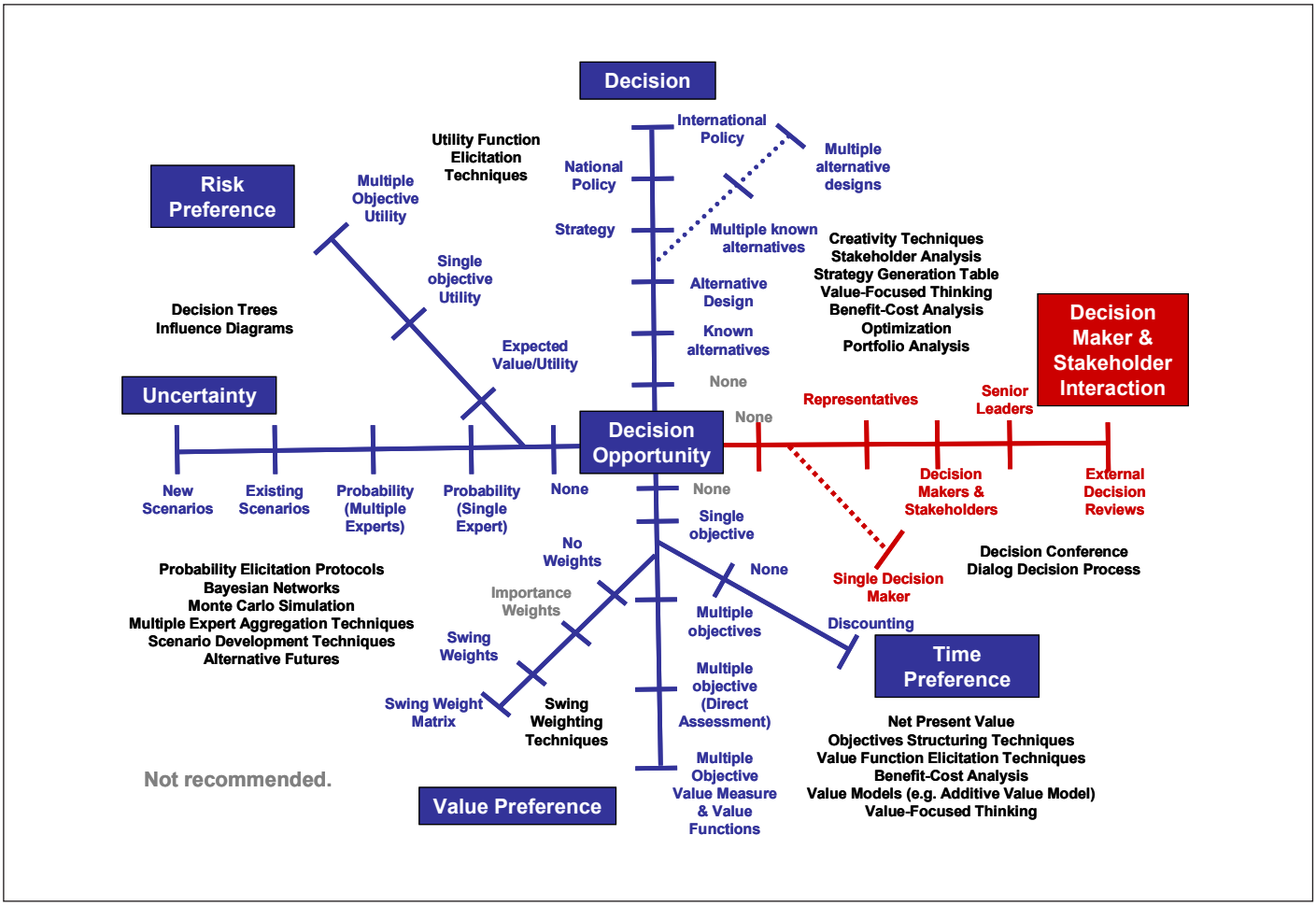

Figure 1: Decision analysis framework.

Four useful techniques to develop alternatives are stakeholder analysis, creativity techniques, the strategy generation table, and Value-Focused Thinking. The stakeholder analysis techniques (Parnell, Driscoll, & Henderson, 2008) used to define the problem can also be used to search for alternatives (e.g., interviews and questionnaires) or design new alternatives (e.g., focus groups). Clemen (1996) describes barriers to creativity and several useful creativity techniques. Howard (1988) uses a strategy generation table to identify decision elements, identify decision options for each element, and develop strategies as an integrated set of decision options for each decision element that span the decision space. Keeney's (1992) Value-Focused Thinking recommends the use of values (see Value Preference Section) to develop better alternatives. Keller and Ho (1988) describe additional alternative generation techniques.

Two useful techniques for portfolio decision making are benefit-cost analysis and optimization. Phillips (2007) uses multiple objective decision analysis to model the benefit and the benefit-cost ratio to determine the order of buy for resource allocation. Kirkwood (1997) combines multiple objective decision analysis for benefits with optimization to develop optimal resource allocation plans subject to a wide variety of cost and programmatic constraints. Many additional portfolio decision analysis techniques have been used that include consideration of uncertainty and risk.

Decision Maker and Stakeholder Interaction

The decision maker and stakeholder interaction dimension captures two important distinctions: the number of decision makers and the level of interaction with decision makers and stakeholders. The first distinction is the number of decision makers: single or multiple. While there are certainly examples of single decision

makers (e.g., your purpose of a car or home when you are single), most problems involve multiple decision makers (e.g., your purchase of a car or home after you are married and most business and public decisions). The second distinction is the level of interaction with decision makers and stakeholders, which can vary from interaction with representatives to decision makers (authorized to make resource decisions) to senior decision makers (C level officers of a corporation or government agency directors) to external review groups (corporate boards or national review groups). The most complexity involves multiple decision makers with senior executive and external reviews.

This dimension is colored red since ineffective stakeholder and decision maker interaction is the primary source of failure of operations research studies to support decision makers. Two proven techniques (both have been used for over 20 years) for decision maker interaction are decision conferences and the dialog decision process. Decision conferences (Phillips, 2007) are leadership and stakeholder conferences that develop requisite multiple objective decision models to enable a shared understanding, consensus decisions, and implementation commitment. Multiple decision conferences can be used to support hierarchical decision making. The dialog decision process (Spetzler, 2007) is a structured process for periodic interaction at major decision milestones with decision makers using decision analysis techniques. The process provides high confidence you are solving the right problem and enables the use of more complex decision analysis models of values and uncertainty for alternative evaluation.

Value and Time Preference

The value and time preference dimension includes three distinctions: time preference, value modeling, and preference weighting. Time preference is usually modeled using a discount rate (Clemen, 1996). Value preference begins with the identification of objectives and value measures (Keeney, 1992). Value modeling can be done with direct assessment or using value functions that model the returns to scale on the value measure (Kirkwood, 1997). Preference weights are assigned to value measures in most value models (e.g., the additive value model, the most common model). Weights depend on the importance of the value measure and the range of variation of the value measure scale. Therefore, decision analysts use swing weights (the swing refers to the variation of the weight as the value measure swings from the lowest value level to highest value level on the scale) and not importance weights. The swing weight matrix (Parnell, Driscoll, & Henderson, 2008) defines the importance and variation in the decision context to aid in assessment and communication of weights.

Common value and time preference techniques include net present value, objectives structuring techniques, value function elicitation techniques, benefit-cost analysis, value models (e.g., additive value model), and Value-Focused Thinking. Net present value is the standard technique for modeling single objectives using a discount rate (Clemen, 1996). Objectives structuring techniques, value function elicitation techniques, value models, and swing weighting are described in Keeney and Raiffa (1976), Keeney (1992), Clemen (1996), and Kirkwood (1997). Keeney (1992) and Parnell, Driscoll, and Henderson (2008) describe Value-Focused Thinking.

Uncertainty and Risk Preference

The fourth, and final dimension, is uncertainty and risk preference. The two major distinctions are uncertainty and risk. Some decision analysis problems do not require uncertainty to be considered. When we need to consider uncertainty, as we have noted, decision analysts use probability to assess their beliefs about uncertainty if they can define a mutually exclusive and collectively exhaustive outcome space. It is simpler to assess probabilities for single experts for each uncertain event, but many complex problems involve multiple experts. For long-range planning problems it is not easy to define the outcome space of the events. For these problems, we sometimes use existing scenarios, or we develop new scenarios to define the strategic planning space (Kirkwood, 1997).

The second distinction is risk preference. As we noted in the value preference dimension, value functions measure returns to scale. We can calculate the expected value of alternatives given the uncertain variables in the problem. Utility functions measure both returns to scale and risk preference (Kirkwood, 1997). Utility functions can have single or multiple objectives and are assessed using lotteries. Single objective utility functions are described as risk adverse (concave for increasing functions), risk neutral (linear), and risk seeking (convex for increasing functions) (Clemen, 1996). The exponential utility function is a common single dimensional utility function.

The important uncertainty techniques include probability elicitation protocols, Bayesian networks, multiple expert aggregation techniques, Monte Carlo simulation, and scenario development techniques including alternative futures. Probability elicitation protocols are described in many of the references including Kirkwood (1997). Bayesian networks (Pearl, 1988) are networks used to model n dimensional probability distributions and obtain inferences before and after observing events. Multiple expert aggregation techniques are described in the literature. Monte Carlo simulation can be used in conjunction with single objective (Clemen, 1996) or multiple objective decision analysis models (Parnell, Driscoll, & Henderson, 2008). Scenario development techniques are described by Kirkwood (1997) and used in large decision analysis studies (Parnell et al., 1998).

The important utility techniques include utility function elicitation techniques, decision trees, and influence diagrams. Utility function elicitation techniques are included in most decision analysis books (Keeney & Raiffa, 1976; Clemen, 1996; and Kirkwood, 1997). Decision trees are an extension of probability trees and used by Raiffa (1968). Decision trees are very flexible—they can be used to solve single and multiple

objective decision analysis problems using value or utility. Influence diagrams, developed by Howard and Matheson, are equivalent to decision trees, but have modeling and communication benefits since the diagram suppresses the details of the branches of the trees (Clemen, 1996).

Decision Analysis Software

In the past 20 years, decision analysis software has been developed to solve decision analysis problems of low, medium, and high complexity. *OR/MS Today* publishes a very useful biennial survey of decision analysis software (Maxwell, 2008). The software tools include decision tree, influence diagram, Monte Carlo simulation, Bayesian network, and multiple objective decision analysis tools.

Decision Analysis Applications

In the past 40 years, there have been a wide variety of decision analysis applications. Few application articles are published due to proprietary information, classified information, and lack of incentives of practioners to publish. Good surveys can be found in Corner and Kirkwood (1991); Keefer, Kirkwood, and Corner (2004); Edwards, Miles, and von Winterfeldt (2007); and Parnell (2007). Decision analysis applications, including the use of decision analysis with other operations research techniques, are published in a wide variety of journals including those of DSI and INFORMS.

Conclusion

My objective of this article is to introduce decision analysis to you in one chart. Figure 1 provides my view of the four decision analysis dimensions, the key concepts, and some of the most common techniques being used by decision analysts to provide value to their clients. In addition, I have included references to some of the major books and literature in the field.

Hopefully, this article will be a useful reference for you the next time you are asked to apply the "Willie Sutton Theory of Operations Research!"

Endnotes

1. I first used an earlier version of this framework in a presentation, "Decision Analysis Tools for Risk Management of Industrial Ports and Harbors," Risk Management Tools For Port Security, Critical Infrastructure, and Sustainability, NATO Advanced Research Workshop, 16-19 March 2006, Venice, Italy.
2. *Decision Analysis Journal* website, http://www.informs.org/site/DA/, accessed December 21, 2008

References

Clemen, R. (1996). *Making hard decisions* (2nd ed.). Duxbury Press.

Corner, J. L., & Kirkwood, C. W. (1991). Decision analysis applications in the operations research literature, 1970-1989. *Operations Research, 39*(2), March-April, 206-219.

Edwards, W., Miles, R., & von Winterfeldt, D. (2007). *Advances in decision analysis—From foundations to applications*. Cambridge Press.

Howard, R. A. (1966). *Decision analysis: Applied decision theory. International Conference on Operations Research*. Boston: Interscience, 55-71.

Howard, R. A. (1988). Decision analysis: Practice and promise. *Management Science, 34*, 679-695.

Howard, R. A., & Matheson, J. E., editors (1983). *The Principles & Applications of Decision Analysis* (Vol. I & II). Strategic Decisions Group.

Keefer, D. L., Kirkwood, C. W., & Corner, J. L. (2004). Perspective on decision analysis applications, 1990–2001. *Decision Analysis, 1*(1), March, 5-24.

Keeney, R. L. (1992). *Value-focused thinking: A path to creative decisionmaking*. Cambridge, Mass.: Harvard University Press.

Keeney, R. L., & Raiffa, H. (1976). *Decision making with multiple objectives preferences and value tradeoffs*. New York: Wiley.

Keller L. R., & Ho, J. (1988). Decision problem structuring: Generating options. *IEEE Transactions on Systems, Man, and Cybernetics, 18*(5), September, 715-728.

Kirkwood, C. W. (1997). *Strategic decision making: Multiobjective decision analysis with spreadsheets.* Belmont, California: Duxbury Press.

Maxwell, D. T. (2008). Improving hard decisions. *OR/MS Today*, October, http://www.lionhrtpub.com/orms/orms-10-08/frsurvey.html

Parnell, G., Conley, H., Jackson, J., Lehmkuhl, L., & Andrew, J. (1998). Foundations 2025: A framework for evaluating future air and space forces. *Management Science, 44*(10), 1336-1350

Parnell, G. S., Driscoll, P. J., & Henderson, D. L., editors. (2008). *Decision making for systems engineering and management.* Wiley Series in Systems Engineering. Wiley & Sons.

Pearl, J. (1988). *Probabilistic reasoning in intelligent systems: Networks of plausible inference*. San Mateo: Morgan Kaufmann, 1988.

Phillips, L. D. (2007). Decision conferencing. In W. Edwards, R. Miles, & D. von Winterfeldt, editors, *Advances in decision analysis—From foundations to applications.* Cambridge Press.

Raiffa, H. (1968). *Decision analysis: Introductory lectures on choices under uncertainty.* Addison-Wesley.

Spetzler, C. (2007). Building decision competency. In W. Edwards, R. Miles, & D. von Winterfeldt, editors, *Advances in decision analysis—From foundations to applications*. Cambridge Press.

Watson, S. R., & Buede, D. M. (1987). *Decision synthesis: The principles and practice of decision analysis.* Cambridge University Press. ■