Summary of Decision Analysis Applications in the Operations Research Literature, 1990–2001

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1. INTRODUCTION

This technical report summarizes applications of decision analysis that appeared in major English language operations research (OR) journals and other closely related journals from 1990 through 2001. The primary purpose of this report is to provide backup information for Keefer et al. (2004), which discusses trends in decision analysis applications. While this technical report stands alone, Keefer et al. (2004) provides analysis that many readers will find useful.

Section 2 of this report summarizes the 86 decision analysis application articles by application area, while Section 3 lists those application articles that emphasize specific methodological and implementation issues, and Section 4 provides concluding comments. Table I lists application articles by application area, while Table II lists the application articles that emphasize methodological and/or implementation issues by the specific issue that is considered. Note that Tables I and II are identical to Tables II and IV, respectively, in Keefer et al. (2004). Also, the reference list at the end of this technical report is identical to the reference list in that paper, and therefore it includes some items that are not discussed in this technical report.

2. SUMMARY OF DECISION ANALYSIS APPLICATIONS

This section summarizes the decision analysis applications articles published in major English language operations research and closely related journals for the period 1990-2001. The following journals were exhaustively reviewed from 1990 through 2001 to determine decision analysis application articles. (The numbers in parentheses are the number of application articles identified in each journal.) The selection criteria used to identify these articles are described in Keefer et al. (2004).

- *Decision Sciences* (1)
- *European Journal of Operational Research* (0)
- *IEEE Transactions on Engineering Management* (4)
- *IEEE Transactions on Systems, Man, and Cybernetics* (1)
- *Interfaces* (40)
- *Journal of Multi-Criteria Decision Analysis* (6)
- *Journal of the Operational Research Society* (1)
- *Management Science* (4)
- *Military Operations Research* (8)
- *Omega, The International Journal of Management Science* (1)
- *Operations Research* (11)
- *Operations Research Letters* (0)
- *Reliability Engineering and System Safety* (2)
- *Research •Technology Management* (2)
- *Risk Analysis* (4)
- *Theory and Decision* (1)

A total of 86 application articles were found in the sixteen journals listed above, and these articles are summarized in this section. Each article is classified into exactly one of the following applications areas and subareas, although some articles could also appropriately be classified into other areas/subareas. The area/subarea selected for a particular article is the one that, on balance, is most emphasized in the article.

- Energy: Bidding and pricing, environmental risk, product and project selection, strategy, technology choice, miscellaneous

- Manufacturing and Services: Finance, product planning, R&D project selection, strategy, miscellaneous
- Medical
- Military
- Public Policy
- General

The application areas are considered in alphabetical order with the exception that the General category is discussed last. Under each application area, the subareas are discussed in alphabetical order with the exception that the Miscellaneous subarea is discussed last for areas containing this subarea. Within each subarea, articles are considered in alphabetical order by the authors' last names, with the exception of articles addressing the same application, which are grouped together. The articles are listed by application area/subarea in Table I.

Energy

Energy applications are classified into bidding and pricing, environmental risk, product and project selection, strategy, technology choice, and miscellaneous.

Bidding and Pricing. Keefer (1995) uses three-point discrete-distribution approximations in conjunction with probability trees to help find the worth from a potential buyer's viewpoint of a refinery that a major oil company had shut down. A conventional economic analysis had proven inconclusive due to the large uncertainties involved. The tree-based approach accommodates the uncertainties, including substantial probabilistic dependence, and displays the judgmentally assessed probabilities explicitly. The results reinforced the position of those in management who wanted to retain the refinery until a substantial offer was made, and this school of thought prevailed.

Keefer et al. (1991) report the development and use of a modeling system to aid Gulf Oil Corporation in allocating bidding capital among blocks at U. S. offshore oil and gas lease sales. This system synthesized methods from decision analysis, nonlinear optimization, and statistics, and evolved substantially with the bidding environment during four years of use when Gulf's bids exceeded $1.5 billion. The paper discusses both modeling and implementation issues and emphasizes the impact on the organization, including how the model helped to focus attention on appropriate objectives, to provide insights on strategic issues such as the merits of partnership bidding, and to stimulate improvements in the quality of the basic data provided to management.

Kidd and Prabhu (1990) present a multiattribute utility model to help a major firm engaged in the construction of power generation and distribution facilities screen bidding opportunities quickly. The model is particularly geared to help the firm's overseas representatives make bid/no-bid decisions in a manner consistent with corporate policies and values without incurring delays from referring the decisions to corporate headquarters. The paper includes a detailed discussion of formal utility assessment methods in this context. The model presented is a scaled-down, disguised version of the actual model developed for the construction firm.

Environmental Risk. Balson et al. (1992) provide an overview of the use of decision and risk analysis methods in analyzing and managing health, environmental, and economic risks from operations in the electric utility industry. They describe the nature and complexity of the risks facing this industry along with the use of appropriate tools from decision analysis and from related areas such as resource economics and cost-benefit analysis. They also include brief descriptions of three specific applications from their consulting practice.

French (1996) reports on efforts to use multiattribute value analysis and decision conferencing to aid in responding to nuclear accidents. He presents a multiattribute value hierarchy that was structured in a series of decision conferences held as part of the International Chernobyl Project and illustrates its use.

He also describes development of a decision support system to aid in choosing short and medium-term countermeasures, which occurred as part of the RODOS project, a European initiative to build a decision support system for emergency response. Finally, he discusses use of decision analysis methods for decisions related to long-term countermeasures and for situations when there is risk of an imminent accident.

Like French (1996), Hämäläinen et al. (2000) report on the use of multiattribute risk and utility analyses in nuclear emergency management as part of the RODOS project. The authors report on a case study of a simulated nuclear accident and how multiattribute analysis might aid in support of decision conferencing aimed at providing early-phase countermeasure strategies. The study highlights several findings: the approach is useful in explaining and justifying group decisions that need to be made rapidly, and modeling prior to actual events can help but decision makers not familiar with the modeling techniques might lose confidence in the approach.

Keeney and von Winterfeldt (1991) describe the massive probability elicitation effort associated with the Nuclear Regulatory Commission's updated reactor safety study known as NUREG 1150, which involved assessment of approximately 1000 probability distributions from about 40 experts. They describe a number of insights obtained from leading this effort, including that an elicitation task of this magnitude can be accomplished in practice if the participants are convinced of its importance. Based on this experience, they recommend an improved comprehensive seven-step process for eliciting probability judgments from multiple experts in complex technical problems.

Procaccia et al. (1997) use Bayesian updating and decision trees to determine optimal maintenance policies for diesel generators supplying standby safety power to nuclear power plants. In doing so, they utilize experts' judgments as a proxy for equivalent maintenance test results in a beta-binomial probability model. The analysis led management to significantly increase the time period between scheduled diesel cylinder replacements.

Product and Project Selection. Borison (1995) describes a decision analysis to help Oglethorpe Power Corporation, a generation and transmission cooperative that provides wholesale power in Georgia, decide whether or not, and if so how, to add an additional transmission line linking with Florida Power Corporation. This multi-step decision analysis utilized influence diagrams, large decision trees (nearly 8000 paths), sensitivity analyses, judgmental probabilities, and decision analysis software within a two week period. The results helped persuade Oglethorpe to shift from a joint venture strategy with Georgia Power to an independent strategy of direct negotiations with Florida Power.

Burnett et al. (1993) describe the long-term use of a project appraisal methodology (PAM) within the Gas Research Institute's annual five-year R&D planning process and discuss its impact on the U. S. natural gas industry. PAM includes a multiattribute scoring function to calculate expected benefits from R&D projects at multiple levels of funding, where the expectations incorporate judgmental probabilities for technical and commercial successes. Benefit-to-cost ratios are calculated from the expected benefits and the funding increments, and these ratios are used to help allocate the R&D budget. The authors conservatively estimate that long-term benefits from using the PAM approach have been in the tens of billions of dollars.

Dyer et al. (1990) describe a decision support system used to help management of a major oil company allocate teams of geologists and geophysicists to oil and gas exploration plays when exploration budgets and manpower are limited. The basic idea is to rank the plays in a consistent fashion based on the value of information to be gained from exploring them. To facilitate the use of the system by non-experts and to avoid direct assessment of probabilities and economic variables that are difficult to assess prior to exploration, they utilize a linearized value-of-information model and estimate the variables needed via a multiattribute model based on attributes (play characteristics) that the explorationists can readily assess. The model was used twice prior to the collapse of oil prices that led to a shift from exploration towards exploitation of existing reserves.

Keeney et al. (1995) use multiattribute value assessment and risk analysis to evaluate the potential reliability benefits of constructing an additional high voltage transmission line for British Columbia Hydro and Power Authority (BC Hydro). Additional alternatives related to line construction concerned timing and whether or not to include automatic load-shedding technology. A multiattribute value model is constructed to serve as a cost-equivalent function to measure the benefits of reducing the probability of power failures. A probabilistic model based on company historical data and judgmental assessments is developed to estimate the effects of the alternatives on the probabilities of electrical outages. The probabilistic and value models are integrated to estimate the expected benefits of the alternatives. The impact of this study on BC Hydro's transmission system planning is also discussed.

Parnell (2001) briefly describes the use of multiobjective decision analysis by the Office of Science and Technology (OST) within DOE to rank environmental cleanup work packages and thus to aid in allocating a limited budget among competing R&D projects. The work-package-ranking system is implemented on database software to facilitate managers' access to several databases in scoring the proposed work packages. OST has successfully used this system for three years (FY 2000 through FY 2002), and its development and use have been noted in DOE testimony in Congress.

Smith and McCardle (1999) provide a tutorial introduction to option pricing methods, focusing on how they relate to decision analysis methods and how methods from these two areas can be integrated in practice. They present an integrated approach that uses options valuation techniques to value market risks and traditional decision analysis techniques to value private, or project-specific, risks—those that cannot be hedged by trading existing securities. They apply this modeling approach along with more conventional models to two real-world exploration and production problems from a major oil and gas company and find that both the modeling of downstream options and the choice of valuation methods affect the results significantly. They discuss a number of lessons learned from developing and applying these models.

Walls et al. (1995) describe software developed to help an exploration division of Phillips Petroleum Company evaluate and rank exploration projects in a manner consistent with the firm's risk tolerance. The software utilizes decision trees and exponential utility functions in conjunction with conventional exploration economics methods to evaluate and rank exploration projects via certainty equivalents. Evaluations at multiple levels (percentages) of participation help identify the best level for the company, and the rankings help in allocating a limited budget among competing projects. The software is used by a number of integrated and independent petroleum exploration firms.

Strategy. Keeney and McDaniels (1992) describe the use of value focused thinking to structure and quantify basic values for British Columbia Hydro and Power Authority (BC Hydro) in the context of strategic planning. They elicit strategic objectives for BC Hydro from three individuals and refine and structure them into a hierarchy. They develop attributes and elicit a multiattribute utility function, and then use it to illustrate value tradeoffs at the strategic level. The results influenced senior planners at BC Hydro in addressing a variety of strategic issues.

Keeney and McDaniels (1999) structure values of multiple stakeholders to help British Columbia Gas (BC Gas) develop an integrated resource plan required by the British Columbia Utilities Commission (BCUC). They elicit values separately from senior executives of BC Gas, members of the BCUC, and representatives of several stakeholder groups, and then structure these into a set of objectives and attributes. These are used to construct an "equivalent-cost" evaluation function, which provides the basis for quantitative evaluation of alternative plans. Among other impacts, this process and its results played a significant role in the quasi-judicial hearing of the BCUC and evoked interesting reactions from the attorneys involved.

Skaf (1999) describes the development and implementation of a portfolio management process and system to help an organization in the upstream oil and gas industry manage a large portfolio of assets in the Gulf of Mexico through exploration, development, and production. The portfolio management system provides analytical support for a variety of decisions including strategic portfolio decisions, lease-

sale bidding decisions, drilling decisions, development configuration and timing decisions, and resource-requirements (staff, equipment, and capital) decisions. The system builds on a rigorous model of the asset life cycle and the key decisions therein, and utilizes a variety of decision analysis tools and concepts. This application has had significant impact on the client organization, and its value-added is in the hundreds of millions of dollars.

Technology Choice. Dyer et al. (1998) describe a multiattribute utility analysis of alternatives to dispose of surplus weapons-grade plutonium for the U. S. Department of Energy (DOE). They construct a hierarchy of objectives and a multiattribute utility function which they use to evaluate thirteen alternatives, conduct sensitivity analyses, and quantify the benefits of deploying multiple technologies simultaneously. Results were presented to the DOE on several occasions. This analysis supported the final DOE recommendation to develop two of the most preferred strategies in parallel.

Jackson et al. (1999) propose a generic multiattribute model for selecting technologies for the DOE's landfill waste site remediation program. Their approach utilizes an array of tools from decision analysis to aid in selecting the appropriate remediation processes for a site (e.g., *treat* versus *contain*) along with a preferred technology for each such process selected. They illustrate use of the model on a demonstration example that contains realistic, but disguised, data.

Perdue and Kumar (1999) briefly report an application to help determine cleanup limits for high-level radioactive waste cleanup at the West Valley (New York) Demonstration Project. A variety of analytical methods are combined in this study, and the results are being used in conjunction with safety criteria to establish proposed tank cleanup limits for ultimate regulatory approval.

Toland et al. (1998) analyze three competing technologies for remediating low-level mixed-waste sites at the Fernald Environmental Management Project. They utilize a variety of analytical methods including Monte Carlo simulation, linear programming, and statistical analysis in developing both process and life-cycle cost models, and use multiattribute decision analysis to integrate the model results and serve as the basis for extensive sensitivity analyses. The study identified huge potential savings at Fernald, and the U. S. Department of Energy plans to extend this work and apply it more broadly.

Von Winterfeldt and Schweitzer (1998) review an analysis conducted to support U. S. Department of Energy decision making on which tritium-supply alternatives to pursue to provide replacement tritium for the U. S. nuclear weapons stockpile. Ten alternatives were assessed with respect to production assurance, cost, and environmental impacts. A dynamic production-simulation model was used with probabilistic assessments of schedule, production capacity, and availability risks. The analysis combined technical, financial, and environmental aspects of the decision and was influential in shaping the final choice by the U. S. Secretary of Energy.

Miscellaneous. Dunning et al. (2001) describe the use of decision analysis to help the New York Power Authority develop a 10-year schedule for refueling its Indian Point 3 Nuclear Power Plant while balancing fish protection, which occurs when the plant is shut down, with costs. They applied a spectrum of decision analysis tools including a decision pyramid, an objectives hierarchy, strategy tables, an influence diagram, a decision tree with over 200 million paths, a standard probability assessment process, and decision analysis software. The analysis provided new insights for scheduling refueling outages at the plant. New York Power Authority decision makers used the model in developing and justifying a schedule for the 10-year period from 1999 through 2008.

Rios Insua and Salewicz (1995) use a multiattribute utility function in an approach to improving control of the monthly operation of a large hydropower reservoir system. The problem involves major uncertainties in the reservoir inflows, multiple competing objectives, and time variation of parameters affecting the operational conditions and tasks. They use dynamic linear models to forecast reservoir inflows, and, due to computational complexity, a heuristic method to find a feasible control strategy. They demonstrate this approach using realistic data and extensive sensitivity analyses for the Lake Kariba system in Africa.

Taha and Wolf (1996) use probability trees and a utility function in the form of a "deficiency statistic" to help Entergy Electric System schedule maintenance outages for generators to improve system reliability in meeting customer demands. They develop discrete probability distributions as approximations to historical data, and use these in conjunction with forecasts and judgmental probabilities as data in the trees. The resulting software tool has been used for several years to help the outage planner identify high-risk weeks and to develop timely maintenance schedules in response to short-notice requests for changes.

Manufacturing and Services

Manufacturing and services applications are classified into finance, product planning, R&D project selection, strategy, and miscellaneous.

Finance. Engemann and Miller (1992) describe a major international bank's use of decision analysis as a framework for making cost-effective risk management decisions. They develop and extensively apply a risk management methodology that uses tools such as decision trees, judgmental probabilities, and simulation to analyze operational risks in probabilistic fashion. The bank utilized this methodology in implementing an ongoing corporate-wide contingency planning program for all their operation's services that remained an industry leader for ten years. The paper includes brief discussions of several specific risk management projects.

Mulvey (1994) describes a methodology developed for the Pacific Financial Asset Management Company for integrating the management of assets and liabilities of pension plans. The resulting integrative asset-liability model extends the Markowitz asset-only allocation model by directly considering projected cash flows from liability scenarios and by also using the expected utility of the pension plan's surplus as the objective function. This approach merges stochastic modeling, nonlinear optimization, and decision analysis and has been implemented on a personal computer.

Product Planning. Beccue (2001) briefly describes how Amgen applied decision analysis to help decide on a strategy for developing and commercializing a new drug in the face of difficult and contentious issues. This application utilized a wide variety of decision analysis tools including a decision tree with approximately 500,000 scenarios for each of eight key strategies that were identified via a strategy table. The decision-analysis process provided key insights, and senior management adopted a new recommended strategy that achieved consensus within the new-product team.

Dillon and Haimes (1996) propose a methodology for structuring and analyzing a variety of network and product decision problems in the telecommunications industry using multiobjective decision trees. They do not follow the conventional practice of discretizing continuous distributions and developing a multiattribute utility function to use in rolling back the decision tree. Instead, they partition continuous distributions and calculate conditional expected values for the partitions to focus on the risks of extreme events, and use Monte Carlo simulation to generate Pareto optimal alternatives for various scenarios considered.

Keeney (2000) briefly describes the construction and use of a multiattribute utility function to help American Express evaluate prospective individual customers in terms of their potential contributions to future market share as well as to future profits. American Express used the resulting four-attribute utility model together with a model for estimating the likelihoods of various customer behaviors to evaluate over 50 million prospective customers. Its use immediately preceded an increase in market share for American Express during the first six months of 1997, which reversed a ten-year decline.

Millet (1994) describes the use of a simple decision tree and an accompanying sensitivity analysis to help convince management of a large logistics operation to waive mandatory annual exhaustive inventory counts in warehouses where sample counts showed high accuracies. Doing so proved to be a very effective incentive for warehouse personnel to begin maintaining accurate inventory records, and the accuracies of inventory reports improved markedly.

Yassine et al. (1999) use probabilistic modeling and decision analysis to evaluate three different approaches for process design in product development: concurrent engineering, sequential task execution, and partially overlapping task execution. They present a real-world example of the development of a cylinder block at a U. S. automotive firm, which includes a decision tree solved via decision analysis software, a comparison of cumulative risk profiles, and a sensitivity analysis. Although not implemented, results indicated that a significant reduction in development time relative to the sequential approach is attainable at the expense of increased manpower cost, and that the choice between the overlapping and concurrent alternatives is sensitive to the tradeoff between development time and manpower cost.

R&D Project Selection. Bruggink (1997) briefly describes the use of decision analysis at Alcoa in evaluating an R&D project to develop a new process step for an aluminum sheet product. This effort utilizes a variety of decision analysis tools including influence diagrams, decision trees, judgmental probabilities, sensitivity analysis, and software. The initial analysis helped focus attention on the critical aspects of the project, and subsequent analyses were used to monitor the project's progress.

Hess (1993) briefly describes two applications of decision analysis to R&D planning at ICI Americas that used relatively simple decision trees and sensitivity analyses. The first is an evaluation of a project to accelerate process research and market development for a new application of a chemical, while the second is an evaluation and ranking of fifty-three aerospace new product proposals. These examples highlight the virtues of using simple decision trees to represent the sequential nature of R&D projects.

Islei et al. (1991) describe the evolution, as well as the long-term use and impact, of a decision support system (DSS) to aid R&D planning at ICI Pharmaceuticals. The system utilizes a hierarchical value structure and a variety of judgmental models to evaluate R&D projects. This DSS has been used to aid in selecting research projects, monitoring portfolios, allocating resources, and terminating projects. It has had a major impact in supporting strategic decision making within the largest research section of ICI Pharmaceuticals, and other ICI departments have applied portions of it as well.

Perdue et al. (1999) present methodology for combining options-pricing techniques and decision analysis tools to evaluate R&D projects at Westinghouse Science and Technology Center. They use an options-pricing model to capture a project's value at the commercial stage, including the value of the option to delay or abandon the project due to unfavorable market conditions. They use a decision tree to represent technical success uncertainties and key research and development decision points. Given the assumptions, data requirements are modest. They demonstrated the approach on thirteen embryonic research projects as a pilot test and subsequently applied it to the complete portfolio of research projects at this research center.

Rzasa et al. (1990) describe an approach based on decision analysis used for R&D portfolio planning at Eastman Kodak. They provide multiple-project examples that illustrate the use of influence diagrams, probability trees, and a resource allocation method. The approach has been successfully implemented and has helped improve both R&D productivity and communications between R&D and business units. Based on several years of experience, they discuss insights obtained, lessons learned, and recommendations for other companies interested in implementing a similar methodology.

Spradlin and Kutoloski (1999) describe a process for R&D portfolio management used at Eli Lilly and Company that utilizes strategy tables to help create meaningful portfolio alternatives, focus analysis on viable choices, emphasize portfolio issues rather than project issues, and facilitate communication with decision makers. Other standard decision analysis tools are employed as necessary for data elicitations, evaluations, sensitivity analyses, etc. The authors briefly describe a real, but disguised, application for a business unit within Lily where the approach successfully produced significant new insights and helped reconcile a budget issue.

Stonebraker et al. (1997) briefly describe the use of decision analysis to help Ford Microelectronics Incorporated decide whether to continue research and development on a potential new

product. This application illustrates the use of a variety of decision analysis tools and includes a sensitivity analysis where a substantial disagreement over the value of a probability does not affect the basic recommendation.

Thurston (1990) uses a multiattribute utility model in long-range analyses of materials selection and design in the automotive industry. The model includes design flexibility as an attribute, measured in terms of the number of body styles per common platform, along with attributes that represent economic and physical design characteristics. The model was applied to five automotive companies in the United States and Europe, and results from two companies are used to illustrate the insights gained. Sensitivity analysis was used extensively and was helpful in providing guidance regarding where additional R&D efforts should be directed.

Strategy. Bodily and Allen (1999) present Strategic Decisions Group's six-step dialogue process for creating, analyzing, choosing, and implementing business strategies. This process integrates concepts and tools from strategy with those from decision analysis and creates structured interactions between a management decision board and a strategy development team. It has been successfully used in strategy consulting for hundreds of companies. The process is illustrated via a hypothetical pharmaceutical firm that represents a composite of real situations encountered in practice in that industry.

Clemen and Kwit (2001) provide an overview of the history of decision and risk analysis (D and RA) at Eastman Kodak Company from the early 1980s until 2001, and discuss informal documentation for 178 DA and related projects conducted between 1990 and 1999. These records encompass a wide variety of project sizes, durations, and types, and indicate that many projects did not lead to complete evaluation of fully developed alternatives due to limited project scope or to termination for reasons such as a client's change in focus. Based on these data, the authors estimate that decision analysis contributed about a billion dollars to the organization between 1990 and 1999. Paradoxically, the future of D and RA at Kodak seems to be in question. Some individuals in the company do use D and RA techniques, but downsizing, transfers, promotions, and retirements over the years reduced the analyst group to a size of one in 2001.

Keeney (1999) reports on the use of value focused thinking to structure objectives for Seagate Software. Interviews to develop objectives were held with numerous key people, many of whom came from recently-acquired companies. This effort helped develop a common vision and sense of values, and also led to developing a list of issues and decision opportunities to address, along with priorities. Seagate followed up on many of the issues and opportunities, and used the identified objectives in developing draft vision and mission statements to help specify the desired future state of the company and how to achieve this state.

Krumm and Rolle (1992) review the history of decision analysis at Du Pont, from early failures through more recent successes and large-scale training efforts. In recent years, more than ten major Du Pont businesses have used a decision and risk analysis process to develop, select, and implement broad business strategies. The authors illustrate the use of this process within Du Pont by describing how the decision board and project team for a real, but disguised, Du Pont business framed their problem, conducted assessments and analyses, chose a strategy, and implemented it. They also discuss both tangible and intangible benefits from the process.

Kusnic and Owen (1992) describe the "unifying vision process" used at General Motors for high-level, multiple decision maker strategic decisions. This process seeks to create a new vision that encompasses all of the visions initially held by the organization's individual decision makers, effectively creating an overall framework for analysis that is the union of the decision makers' original frames. The authors discuss implementation of this approach and contrast it with more conventional large-scale corporate decision analysis, including differences in the orientation of the process steps, in the structure of the dialog process, and in the makeup of the teams involved. They present a real, but disguised, example in which this approach led to creating and adopting a new strategy that every decision maker preferred to any of the strategies proposed initially.

Matheson and Matheson (1999) describe the benefits of incorporating an "outside-in" perspective in developing effective business strategies. The idea is to work inward from the motivation and the forces acting on customers toward their implications for the company, and then to develop appropriate models. They illustrate the application of this approach by describing a strategic decision analysis for a real, but disguised, major video-game-software company. This analysis provided key insights and led to a major shift in the company's basic business strategy.

Quaddus et al. (1992) provide a general discussion of decision conferencing and describe an application to strategic planning in a voluntary organization that provides services to people with physical and mental disabilities. Eleven top executives of the organization participated at a specially equipped facility in a two-day decision conference that utilized an objectives hierarchy, a multattribute utility model, sensitivity analysis, and decision analysis software. The decision-conferencing process increased understanding among the participants and produced agreement on the strategic direction to pursue.

Miscellaneous. Chien and Sainfort (1998) consider meals served to nursing home residents as portfolios of food items and develop "top-down" meal-level attributes for evaluating combinations of food items while taking food interactions into account. For example, one attribute is the probability that a combination of foods will have a good overall flavor, and this is calculated using Bayesian decomposition coupled with conditional independence. Using judgments from a nutritionist, the authors utilized these attributes in conjunction with a simple multiattribute value model to pilot test their approach.

Medical

Brown (1997) uses multiattribute utility analysis and decision trees to evaluate vision correction alternatives for highly myopic adults. Using a combination of personal data and data from the literature he evaluates surgical procedures (radial keratotomy and photorefractive keratectomy) as well as non-surgical alternatives involving contact lenses and eyeglasses. He considers the timing of decisions and includes multiple sensitivity analyses. The results helped him make his near-term decision, which was to delay surgery at least temporarily.

Feinstein (1990) describes the use of Bayes' rule in conjunction with a decision tree to help the Athletic Board of Governance of Santa Clara University consider a proposal to test athletes for drug use. The model helped focus attention on appropriate values for the relevant probabilities and for the costs of possible errors. Sensitivity analysis showed that the proposed testing was inappropriate over the plausible range of values for problem parameters. The analysis was persuasive: the board recommended that the university not begin drug testing of student athletes, and the president accepted the recommendation.

Hazen et al. (1998) provide an introduction to stochastic trees and related tools and their use in medical decision making. Stochastic trees combine features of continuous-time Markov chains with those of decision trees and enable time to be modeled as a continuum where health state transitions can occur at any instant. They can also accommodate patients' preferences regarding risk and quality of life. The authors illustrate how these tools have been applied to analyze the decision to undergo a total hip replacement from the perspectives of an individual patient (via utility analysis) and of society (via cost-effectiveness analysis).

Smith and Winkler (1999) use a simple Bayesian model to help assess the probability that a newborn baby who had tested positive for a potentially very serious enzyme deficiency actually has that deficiency. Interpreting the test result was complicated by uncertainty both about the false-positive rate, since this was the first positive result for an experimental test, and about the base rate. The analysis produced a probability that was much smaller than the doctor's initial estimate. The paper interprets this discrepancy in terms of common probability assessment heuristics and discusses the role and value of such diagnostic tests in general.

Winkler et al. (1995) apply a formal process for encoding experts' probability judgments relative to the risks of chronic lung injury from long-term ozone exposure. In particular, they elicited

probabilities over population response rates from six health experts. Their approach highlights the potential benefits in a complex risk assessment of bringing experts together after an initial round of individual assessments to share information with each other and with the risk assessment team. The results characterize scientific judgments regarding chronic effects of ozone and provide both probabilities and qualitative insights of interest to the scientific community, policymakers, and the general public.

It is worth noting that decision analysis methods are now extensively applied in medical decision making. Much of this work is reported in specialized medical journals, and the interested reader is referred to the journal *Medical Decision Making* and the web site of the Society for Medical Decision Making (www.gwu.edu/~smdm) as starting points for learning more about medical decision analysis applications.

Military

Bresnick et al. (1997) describe an analysis initiated by the Joint Requirements Council of the U. S. Joint Chiefs of Staff to develop a process for making reconnaissance force mix decisions. The approach utilizes a multiattribute value function to capture benefits and system lifecycle costs to represent costs. A cost-benefit analysis using a Pareto-optimal efficient frontier approach is then used to aid in resource allocation. The approach was implemented via a series of decision conferences that were instrumental in gaining the participation, cooperation, and expertise needed from a diverse set of military and civilian representatives.

Buede and Bresnick (1992) discuss applications of decision analysis to military systems acquisition. They define four phases in the acquisition process for major military systems and provide a brief description of an application in each phase. They also briefly describe their long-term successful involvement in helping the U. S. Marine Corps set project priorities to aid in resource allocation within the budgeting process, and they provide a list of other successful applications of decision analysis to military systems acquisition. They have used multiattribute value analysis, resource allocation techniques, and decision conferencing extensively in this work.

Burk and Parnell (1997) describe the role of value-focused thinking and analysis in SPACECAST 2020, a large-scale U. S. Air Force study of future system concepts and supporting technologies for military space operations. A value hierarchy was developed based on existing military policy documents, and an additive multiattribute value function was used to evaluate alternative systems concepts. This evaluation phase, including a sensitivity analysis of the weights, was successfully completed on a tight schedule in spite of alternatives that were complex and incompletely defined. The study was widely accepted and was instrumental in the commissioning of the Air Force 2025 study, which is discussed below. Rayno et al. (1997) examine the assumptions of the SPACECAST 2020 value model and conduct a sensitivity analysis that considers modifications in the single-attribute value functions and in the form of the overall multiattribute value function. They conclude that the additive value function is adequate, but recommend modifying the forms of the single-attribute value functions in future work.

Davis et al. (1999, 2000) present a methodology for evaluating and expanding a command, control, communications, and computer network. They use a network flow optimization model to identify bottlenecks and to provide the focus for generating expansion plans, and they use an expansion model to optimize the network expansion. Based on information from the literature and from experienced military decision makers, they develop a hierarchy of objectives and then a multiattribute value model to facilitate comparisons and evaluations of alternatives and to serve as the objective function for the expansion model. They present an illustrative military example with realistic data and indicate that the methodology has been adapted and applied to several operational settings.

Doyle et al. (2000) provide another example of value-focused thinking in the U. S. military, applied this time to modeling offensive information operations. Such operations are efforts to influence an adversary's decision making capabilities by targeting the adversary's strategic information resources, such as "the information itself, people who use or control information, and systems and processes that

organize communicate, or transform information into usable intelligence" (Doyle et al 2000, p. 5). Two hierarchical value models were built, one for values and one for costs. A weighted-additive value function was then used to model a realistic scenario involving information options for dealing with a hypothetical third-world facility making and storing weapons of mass destruction.

Griggs et al. (1997) describe the development of an air mission planning model for use in a combat simulation model. The crux of the planning model is a mixed integer programming formulation (MIP) that allocates the optimum number and type of aircraft and munitions against each target, but its data vary with the uncertain state of the weather. The plan with the highest expected value is obtained by solving a simple decision tree that utilizes solutions to the MIP for each possible state of the weather. A reduced-scale example is provided.

Jackson et al. (1997) and Parnell et al. (1998) describe the use of value focused thinking in Air Force 2025, a major U. S. Air Force study to identify key system concepts and technologies for achieving air and space dominance in 2025. This study built upon the methodology of SPACECAST 2020 and involved over 200 military experts for more than a year. A value hierarchy was developed with the aid of creativity techniques, and an additive value model with 134 attributes was used to score forty-three futuristic systems concepts. Six scenarios describing possible future states of the world were constructed, and a set of value-function weights was assessed for each scenario to investigate the sensitivity of system preferences to the scenarios. The study successfully produced a number of system concepts for employing air and space power in the future and identified seven high-leverage technologies needed to support the high-scoring systems.

Kerchner et al. (2001) discuss the use of value-focused thinking to model psychological operations (PSYOP) choices for the military. PSYOPs are the use of psychological dimensions in an effort to influence an opponent's attitudes and actions. Based on already established military doctrine, along with input from a range of military personnel, an objectives hierarchy involving 72 evaluation measures was established. A multiattribute additive value model was then used to choose from a set of strategy options in a hypothetical scenario involving a governmental overthrow attempt on the fictional nation of Cortina. The model is shown to be flexible enough for use in real PSYOP situations and includes objectives not previously modelled in these situations.

Parnell et al. (2001) develop a future value model to assist the U. S. National Reconnaissance Office in its technology development efforts and in assessing the future value of current technology projects. The organization's main goal is to "provide technology innovations to revolutionize global reconnaissance" (Parnell et al. 2001, p. 21) and the authors were tasked with developing a model of "audacious objectives" to challenge R&D managers. They evaluate R&D projects using a combination of three techniques: strategic assessment of future opportunities and challenges, multi-objective decision analysis based on value-focused thinking, and multiple perspective portfolio analysis.

Stafira et al. (1997) present a decision analysis methodology for evaluating dissimilar systems used to support U. S. counterproliferation efforts against weapons of mass destruction. They develop an influence diagram to represent the U. S. counterproliferation decision process and also use a variety of other decision analysis tools including a decision tree, a two-attribute utility function, value of control concepts, and sensitivity analysis. They evaluated nine systems from a U. S. Air Force war game as an illustrative example. Further development and use of this methodology by government agencies was planned.

Public Policy

Bana e Costa (2001) uses multi-criteria decision analysis in evaluating public policy alternatives for allocating limited funds among inter-municipal road-links in the Lisbon Metropolitan Region. Using decision analysis software and judgments from technical staff of the executive body of mayors from the 18 municipalities, the study team constructed a multiattribute value model and applied it to evaluate four realistic "reference" policy options (packages of projects). They subsequently developed two improved

policy options having outcomes that reduced conflicts among the interests of the municipalities. The study provided the mayors with useful information concerning the extent of negotiation required to reach agreement on a specific policy option.

Hall et al. (1992) develop a constrained zero-one optimization model with an exponential value function to assist the U. S. National Cancer Institute with a proposal funding decision. The decision is modeled as a portfolio selection problem where an uncertain budget is to be allocated to various states in the U. S. to fund smoking reduction initiatives. A modified Delphi approach is used to gather preference information for the model, and a parametric analysis incorporating sub-objectives as constraints generates an efficient frontier of candidate portfolio solutions. These formalized methods were used to reduce the impact of political pressures on the decision makers.

Heger and White (1997) make a case for using influence diagrams to help optimize choices for obtaining additional field data in environmental remediation and waste management problems. They present a general influence diagram model for monitor-and-treat type environmental problems where "data worth" (value of information) is an issue. They illustrate the approach with a specific numerical example involving the level of arsenic in the municipal water supply and in the discharge streams of Albuquerque, New Mexico.

Jones et al. (1990) discuss the development and potential use of a model for considering energy policy options in the United Kingdom. The model allows users to select fifteen objectives from a predetermined list of forty-one objectives to value five decision alternatives/scenarios for the year 2010. The model then determines the value profile of each of the alternatives for each of the 15 objectives using an additive value function, and stores these value sets for later consideration. The model and stored value sets served as a vehicle for communicating the values and preferences of roughly 250 individuals across more than 100 organizations who are stakeholders in U. K. energy policy-making.

Keeney (1997) uses decision analysis in conjunction with a simplified probabilistic exposure model to investigate the potential health effects of a proposed moratorium on new electricity transmission lines. The analysis indicates that building additional transmission lines could in many cases result in lower exposure of the populace to electromagnetic fields having possible health effects than loading existing lines with more current. Consequently, rather than a blanket moratorium of building new transmission lines, the recommendation is to consider proposed transmission lines on a case-by-case basis.

Keeney and McDaniels (2001) develop a framework based on value-focused thinking for the consideration of climate change policy choices. Their premise is that it is difficult to make decisions today when the consequences of the considered alternatives are potentially revealed over hundreds of years. Thus, they use path dependence ("learning by doing") concepts to show how near-term consequences can be considered along with the future decisions that might arise after seeing these consequences unfold (say, in 20 years). This adaptive approach is used to consider the Kyoto Accord and the difficulties inherent in its ability to meet near- and long-term objectives.

Keeney and von Winterfeldt (1994) provide a framework for considering policy options for the disposal of nuclear waste over the next 100 years. They develop a decision analysis model having a linear additive measurable value function. They use sensitivity analysis to explore the uncertainties that might impact the disposal policy over that period, including possible technological advances and a cure for cancer from radiation exposure. They also consider framing the problem more broadly—e.g., the money available now for waste disposal could be invested in an endowment fund and be spent 100 years from now when permanently solving the nuclear waste problem might be feasible. They conclude that the current policy for storing waste in underground repositories is misguided, since the assumptions underlying this policy are inappropriate.

Keeney et al. (1990) offer a way to incorporate both public values and expert assessments in policy making. Their "public value forum" combines focus groups and direct value elicitation methods. The focus groups are with laypeople, from whom multiattribute utility functions and tradeoff information

are elicited over a pre-specified list of objectives. This value information is then combined with assessments regarding possible future scenarios made by experts. The application that is presented involves consideration of four alternative energy policy scenarios over the next fifty years in the Federal Republic of Germany. Although time consuming and expensive to carry out, this process showed that discrepancies within and between groups and experts can be resolved using the approach, resulting in potentially useful input into policy making.

Lehmkuhl et al. (2001) use value-focused thinking to analyze the U. S. Department of Defense's decision, based on a presidential directive, to modernize the global positioning system (GPS). The goal of the analysis was to choose from several signal, or waveform, satellite transmission alternatives. The analysis took into account the diverse needs of military and civilian users of the system and proved helpful in identifying relevant data needs, quantifying intuition, explaining the counter-intuitive, and dealing with bias. It further led to a different recommendation than what had originally been supported by key stakeholder groups.

McDaniels (1995) provides an *ex post* analysis of a recent decision in fisheries management to show how decision analysis could be employed. The decision was whether or not the opening day for salmon fishing should have been delayed. The analysis showcased the value of incorporating subjective preferences and probabilities when the time frame for decision making is compressed. The analysis showed that delaying the opening a single day would have resulted in the equivalent of $7.9 million in benefits.

Reagan-Cirincione et al. (1991) discuss the use of multiattribute value modeling, decision conferencing, and system dynamics to address public policy issues affecting multiple stakeholders. They describe an application for the New York State Insurance Department that involved developing and evaluating multi-faceted strategic policy options for medical malpractice insurance. In addition to investigating sensitivities to the multiattribute weights and to the ratings of policies with respect to attributes, they use sensitivity analysis to highlight the strengths and weaknesses of the three original options, thereby producing a hybrid option combining elements of these three. Results of the analysis were an integral part of the Insurance Department's report to the New York State Legislature.

Spector (1993) discusses the use in negotiations of decision analysis methods, including decision trees, multiattribute utility/value models, and sensitivity analysis. In particular, he emphasizes their use in the prenegotiation phase, when parties are formulating their positions and strategies and evaluating possible reactions and outcomes. He briefly describes a project of the International Institute of Applied Systems Analysis in support of the United Nations Conference on Environment and Development that used multiattribute models to evaluate potential coalition building and preference adjustments among participants.

Taylor et al. (1993) explore the value of additional information when deciding on environmental control strategies for potentially carcinogenic compounds. Quantitative expressions are developed to measure the social costs of chemicals with uncertain cancer potencies, and a value of information analysis is performed to determine the benefit of pursuing improved potency information via animal tests, which are expensive and generate imperfect information. Analysis shows that the value of this information depends on the anticipated level of human exposure, the prior probability that an untested chemical is a carcinogen, the degree to which test outcomes on animals equate to similar results in humans, and other uncertainties, such as the natural rates of cancer in test animals.

General

Six articles do not fit into the classifications listed above.

Baker et al. (2000) discuss an equipment funds allocation decision problem at the U. S. Air Force Academy. A multiattribute value model, coupled with the Delphi Method for determining consensus for the 13 attribute weights, was used to rank 45 equipment requests from 19 departments and supporting staff agencies. The model purposely accounted only for contribution to value when determining the

benefits of each item, and not its cost. This approach avoided a possible double counting of costs and ensured funding choices were based on performance, which is presented as a desirable property for decision analyses by mission-oriented public sector organizations.

Hurley (1998) considers a situation in U. S. football where a trailing team faces fourth-and-goal in the closing moments of the game. He argues that the decision for the fourth-and-goal situation should be made prior to deciding what to do on first-and-goal, since the first-and-goal decision may be impacted by what will be done on fourth-and-goal.

Keller and Kirkwood (1999) describe the history and motivations surrounding the merger of The Institute of Management Sciences (TIMS) and the Operations Research Society of America (ORSA) to form the Institute for Operations Research and the Management Sciences (INFORMS). Fifty-four objectives (later reduced to fourteen objectives) were considered using a weighted-additive value model to rank-order various merger options, as well as the option of remaining separate. This application mainly demonstrates the *process* of applying decision analytic techniques to strategy formulation and implementation, rather than the technical details of arriving at an optimal solution using such techniques.

Matzkevich and Abramson (1995) survey and synthesize research from the decision analysis and artificial intelligence (AI) communities involving influence diagrams and belief networks, which essentially are influence diagrams without decision nodes that are used for Bayesian inference. Most of the article consists of conceptual background, theoretical foundations, and algorithms, but the authors also discuss "normative systems," which are AI systems based on influence diagrams or belief nets and thus on Bayesian principles. In particular, they provide brief descriptions of several implemented systems in areas including medical diagnosis, energy price and demand forecasting, and machine vision.

Paté-Cornell and Fischbeck (1994) perform a probabilistic risk analysis of failure of the exterior surface tiles on the US space shuttle orbiter. Expert opinion and the experience of the first 30 shuttle flights were used to build a decomposed model of risk for various zones on the shuttle's tile-bearing surface. The analysis showed that roughly 15% of the tiles contribute to 85% of the risk of failure. The study further highlighted organizational factors that contribute to potential tile failure risks and led to various policy changes in the management and maintenance of the tiles.

Vári and Vecsenyi (1992) discuss several effects of and lessons learned from using decision analysis methods during decision conferencing in Hungary. A number of socio-economic and market changes during the 1980's in Hungary led to the use of decision conferencing techniques in organizations seeking ways to adjust to these changes. Twenty-six conferences involving twenty-three decisions are described. Thirty-nine organizations (manufacturing, service, and government) were involved, dealing with decisions considering tactical problems, organizational strategy, negotiation, and interorganizational issues.

3. METHODOLOGICAL AND IMPLEMENTATION ISSUES

Table II lists those application articles that present significant detail about a particular decision analysis methodological or implementation issue. [This table is identical to Table IV in Keefer et al. (2004).] Many articles deal with nearly all of the methodological and implementation issues shown in that table, but an article is included in Table II only if it provides detailed information on a topic. Thus, this table can be used to identify articles that emphasize a particular methodological or implementation issue. Articles are included in the strategy and/or objectives generation category if they discuss overall decision strategy and/or present an objectives or value hierarchy, or discuss the decision structuring process in detail. Articles are included in the problem structuring/formulation category if they describe and present a decision tree and/or influence diagram and discuss its development and use. The probability assessment category includes articles that discuss the elicitation of subjective probabilities, probabilistic dependence or independence, and/or risk assessment. Similarly, articles are listed in the utility assessment category if subjective utility/value functions or tradeoffs between attributes are

discussed in depth. Articles are listed in the sensitivity analysis category if tornado or rainbow diagrams are presented and/or statistical or mathematical approaches to model sensitivity analysis are discussed.

The communication/facilitation category includes articles that discuss the role of the analyst, how decision analysis facilitates the decision process, and/or how communication channels are opened due to the use of the approach. Articles are included in the group issues category if there is discussion about aggregating individual preferences into a group function, or discussion of the solicitation and treatment of multiple individual inputs into the preference or probability model. Finally, the implementation category includes articles that discuss post-modeling issues related to implementing chosen alternatives or the value of decision analysis techniques for the individuals or organization in their future decision making efforts.

5. CONCLUDING COMMENTS

This technical report provides summaries of decision analysis applications appearing in major English language operations research journals and other closely related journals from 1990 through 2001. These applications cover a broad range of decisions in both the public and private sectors, and they demonstrate that decision analysis continues to be a widely used approach for a variety of strategic and tactical decisions.

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Table I

Application Articles Listed by Application Area

Energy

Bidding and Pricing: Keefer (1995), Keefer et al. (1991), Kidd and Prabhu (1990).

Environmental Risk: Balson et al. (1992), French (1996), Hämäläinen et al. (2000), Keeney and von Winterfeldt (1991), Procaccia et al. (1997).

Product and Project Selection: Borison (1995), Burnett et al. (1993), Dyer et al. (1990), Keeney et al. (1995), Parnell (2001), Smith and McCardle (1999), Walls et al. (1995).

Strategy: Keeney and McDaniels (1992), Keeney and McDaniels (1999), Skaf (1999).

Technology Choice: Dyer et al. (1998), Jackson et al. (1999), Perdue and Kumar (1999), Toland et al. (1998), von Winterfeldt and Schweitzer (1998).

Miscellaneous: Dunning et al. (2001), Rios Insua and Salewicz (1995), Taha and Wolf (1996).

Manufacturing and Services

Finance: Engemann and Miller (1992), Mulvey (1994).

Product Planning: Beccue (2001), Dillon and Haimes (1996), Keeney (2000), Millet (1994), Yassine et al. (1999).

R&D Project Selection: Bruggink (1997), Hess (1993), Islei et al. (1991), Perdue et al. (1999), Rzasa et al. (1990), Spradlin and Kutoloski (1999), Stonebraker et al. (1997), Thurston (1990).

Strategy: Bodily and Allen (1999), Clemen and Kwit (2001), Keeney (1999b), Krumm and Rolle (1992), Kusnic and Owen (1992), Matheson and Matheson (1999), Quaddus et al. (1992).

Miscellaneous: Chien and Sainfort (1998).

Medical

Brown (1997), Feinstein (1990), Hazen et al. (1998), Smith and Winkler (1999), Winkler et al. (1995).

Military

Bresnick et al. (1997), Buede and Bresnick (1992), Burk and Parnell (1997), Davis et al. (1999), Davis et al. (2000), Doyle et al. (2000), Griggs et al. (1997), Jackson et al. (1997), Kerchner et al. (2001), Parnell et al. (1998), Parnell et al. (2001), Rayno et al. (1997), Stafira et al. (1997).

Public Policy

Bana e Costa (2001), Hall et al. (1992), Heger and White (1997), Jones et al. (1990), Keeney (1997), Keeney and McDaniels (2001), Keeney and von Winterfeldt (1994), Keeney et al. (1990), Lehmkuhl et al. (2001), McDaniels (1995), Reagan-Cirincione et al. (1991), Spector (1993), Taylor et al. (1993).

General

Baker et al. (2000), Hurley (1998), Keller and Kirkwood (1999), Matzkevich and Abramson (1995), Paté-Cornell and Fischbeck (1994), Vári and Vecsenyi (1992).

Table II

Application Articles Addressing Methodological and Implementation Issues

Strategy and/or Objectives Generation

Baker et al. (2000), Bana e Costa (2001), Bodily and Allen (1999), Bresnick et al. (1997), Brown (1997), Buede and Bresnick (1992), Burk and Parnell (1997), Burnett et al. (1993), Chien and Sainfort (1998), Davis et al. (1999), Davis et al. (2000), Doyle et al. (2000), Dyer et al. (1998), Dyer et al. (1990), French (1996), Hämäläinen et al. (2000), Islei et al. (1991), Jackson et al. (1997), Jackson et al. (1999), Jones et al. (1990), Keeney (1999b), Keeney and McDaniels (1992, 1999, 2001) Keeney et al. (1995), Keeney and von Winterfeldt (1994), Keeney et al. (1990), Keller and Kirkwood (1999), Kerchner et al. (2001), Krumm and Rolle (1992), Kusnic and Owen (1992), Lehmkuhl et al. (2001), McDaniels (1995), Parnell et al. (1998), Parnell et al. (2001), Perdue and Kumar (1999), Rayno et al. (1997), Reagan-Cirincione et al. (1991), Skaf (1999), Spector (1993), Spradlin and Kutoloski (1999), von Winterfeldt and Schweitzer (1998).

Problem Structuring/Formulation (via Decision Trees and Influence Diagrams)

Balson et al. (1992), Bodily and Allen (1999), Borison (1995), Brown (1997), Dillon and Haimes (1996), Dunning et al. (2001), Dyer et al. (1998), Dyer et al. (1990), Engemann and Miller (1992), Feinstein (1990), Griggs et al. (1997), Hazen et al. (1998), Heger and White (1997), Hess (1993), Jackson et al. (1999), Keefer (1995), Keefer et al. (1991), Keeney (1997), Keeney et al. (1995), Keeney and von Winterfeldt (1994), Krumm and Rolle (1992), Matheson and Matheson (1999), Matzkevich and Abramson (1995), Millet (1994), Perdue et al. (1999), Quaddus et al. (1992), Rzasa et al. (1990), Smith and McCardle (1999), Smith and Winkler (1999), Stafira et al. (1997), Stonebraker et al. (1997), Taylor et al. (1993), Walls et al. (1995), Yassine et al. (1999).

Probability Assessment

Balson et al. (1992), Chien and Sainfort (1998), Dillon and Haimes (1996), Dunning et al. (2001), Dyer et al. (1990), Feinstein (1990), Keefer (1995), Keeney et al. (1995), Keeney and von Winterfeldt (1991), Keeney and von Winterfeldt (1994),McDaniels (1995), Paté-Cornell and Fischbeck (1994), Perdue et al. (1999), Procaccia et al. (1997), Smith and McCardle (1999), Smith and Winkler (1999), Stafira et al. (1997), Taha and Wolf (1996), Taylor et al. (1993), von Winterfeldt and Schweitzer (1998), Winkler et al. (1995), Yassine et al. (1999).

Utility/Value Assessment

Baker et al. (2000), Bana e Costa (2001), Bresnick et al. (1997), Burk and Parnell (1997), Doyle et al. (2000), Dyer et al. (1998), Dyer et al. (1990), Hall et al. (1992), Hämäläinen et al. (2000), Hazen et al. (1998), Jackson et al. (1997), Jackson et al. (1999), Keeney (2000), Keeney and McDaniels (1992), Keeney and McDaniels (1999), Keeney et al. (1995), Keeney and von Winterfeldt (1994), Keeney et al. (1990), Kerchner et al. (2001), Kidd and Prabhu (1990), Lehmkuhl et al. (2001), McDaniels (1995), Mulvey (1994), Parnell et al. (1998), Rayno et al. (1997), Rios Insua and Salewicz (1995), Thurston (1990), Walls et al. (1995).

Sensitivity Analysis

Baker et al. (2000), Bana e Costa (2001), Bodily and Allen (1999), Brown (1997), Doyle et al. (2000), Dyer et al. (1998), Hess (1993), Jackson et al. (1999), Keeney and von Winterfeldt (1994), Kerchner et al. (2001), Lehmkuhl et al. (2001), McDaniels (1995), Millet (1994), Perdue et al. (1999), Quaddus et al. (1992), Reagan-Cirincione et al. (1991), Smith and Winkler (1999), Spradlin and Kutoloski (1999), Stafira et al. (1997), Taylor et al. (1993), Thurston (1990), Walls et al. (1995), Yassine et al. (1999).

Communication/Facilitation

Bodily and Allen (1999), Borison (1995), Bresnick et al. (1997), Feinstein (1990), French (1996), Hämäläinen et al. (2000), Islei et al. (1991), Jones et al. (1990), Keefer (1995), Keefer et al. (1991), Keeney (1999b), Keeney and McDaniels (1992), Keeney and McDaniels (1999), Keeney et al. (1995), Keeney et al. (1990), Keller and Kirkwood (1999), Kerchner et al. (2001), Krumm and Rolle (1992), Kusnic and Owen (1992), Lehmkuhl et al. (2001), McDaniels (1995), Quaddus et al. (1992), Reagan-Cirincione et al. (1991), Skaf (1999), Spector (1993), Spradlin and Kutoloski (1999), Vári and Vecsenyi (1992), von Winterfeldt and Schweitzer (1998), Winkler et al. (1995).

Group Issues

Baker et al. (2000), Bana e Costa (2001), Bresnick et al. (1997), Hämäläinen et al. (2000), Keeney and McDaniels (1999), Keeney et al. (1990), Keller and Kirkwood (1999), Kusnic and Owen (1992), Quaddus et al. (1992), Reagan-Cirincione et al. (1991), Vári and Vecsenyi (1992), Winkler et al. (1995).

Implementation

Baker et al. (2000), Bodily and Allen (1999), Burk and Parnell (1997), Doyle et al. (2000), Dyer et al. (1990), Engemann and Miller (1992), Islei et al. (1991), Jackson et al. (1997), Keefer et al. (1991), Keeney and McDaniels (1992), Keeney and McDaniels (1999), Keeney et al. (1995), Keeney and von Winterfeldt (1994), Keeney et al. (1990), Keller and Kirkwood (1999), Kerchner et al. (2001), Kusnic and Owen (1992), Lehmkuhl et al. (2001), Parnell et al. (1998), Parnell et al. (2001), Paté-Cornell and Fischbeck (1994), Rzasa et al. (1990), Skaf (1999), Smith and Winkler (1999), Spradlin and Kutoloski (1999), Vári and Vecsenyi (1992), Walls et al. (1995).