MULTIPLE CRITERIA DECISION MAKING, MULTIA TTribute UTILITY THEORY: THE NEXT TEN YEARS*

JAMES S. DYER, PETER C. FISHBURN, RALPH E. STEUER, JYRKI WALLENIUS 
AND STANLEY ZIONTS

College of Business Administration, University of Texas, Austin, Texas 78712
AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey 07974
College of Business Administration, University of Georgia, Athens, Georgia 30602
Helsinki School of Economics, Helsinki, Finland
School of Management, State University of New York, Buffalo, New York 14260

Management science and decision science have grown exponentially since midcentury. Two closely-related fields central to this growth are multiple criteria decision making (MCDM) and multiattribute utility theory (MAUT). This paper comments on the history of MCDM and MAUT and discusses topics we believe are important in their continued development and usefulness to management science over the next decade. Our aim is to identify exciting directions and promising areas for future research.

(DECISION MAKING; MULTIATTRIBUTE; MULTIPLE CRITERIA)

1. Introduction

We begin our account of MCDM and MAUT by outlining contributions that have given rise to the fields. This is followed by comments about the international perspective of MCDM and MAUT and a description of the fields. The rest of the paper is devoted to promising topics for continued and new research in MCDM/MAUT, including its connections to decision support systems, behavioral realities, robustness, and decision heuristics. Implementation concerns that focus on computer software and applications are also summarized.

Because the paper reflects the backgrounds and interests of its authors, it is not a survey. Many topics are discussed only briefly. Reviews and texts that provide a deeper background and further references include Fishburn (1970), Keeney and Raiffa (1976), Cohon (1978), Goicoechea, Hansen and Duckstein (1982), Farquhar (1983), Yu (1985), Steuer (1986), von Winterfeldt and Edwards (1986), and Aksoy (1990).

2. Contributions

From the beginning, many of the topics in MCDM have been optimization-related. Goal programming, conceived by Charnes and Cooper (1961), was an early contribution. While goal programming's development continued under the leadership of Lee (1972) and Ignizio (1976), vector optimization algorithms for computing the set of all nondominated solutions of a multiple objective program attracted considerable interest (Geoffrion 1968; Evans and Steuer 1973; Yu and Zeleny 1975; Gal 1977; Isermann 1977; Bitran 1979; Ecker, Hegner, and Kouada 1980). Because the size of the nondominated set can make it difficult to single out a final solution, interactive procedures (Benayoun et al. 1971; Geoffrion, Dyer, and Feinberg 1972; Zions and Wallenius 1976; Wierzbicki 1980; Spronk 1981; Steuer and Choo 1983; Nakayama and Sawaragi 1984; Korhonen and Laakso 1986) moved to center stage in the 1980s.

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On the MAUT side, the additive value model for multiple objectives of Churchman and Ackoff (1954) and others was axiomatized by Debreu (1960), Luce and Tukey (1964), Krantz (1964), and Scott (1964). Later summaries and extensions appear in Krantz, Luce, Suppes and Tversky (1971) and Wakker (1989). The earlier axiom systems were followed by axioms for multiattribute models in expected utility theory by Pollak (1967), Keeney (1968), Fishburn (1970) and others. A good summary is given by Keeney and Raiffa (1976), and a synthesis of these models appears in Dyer and Sarin (1979).

With these contributions as foundations, much of the work in the ’70s and ’80s has been common to both MCDM and MAUT. For example, the French school has developed several approaches, including the ELECTRE methods that employ outranking relations (see Roy 1973) as well as methods that use piecewise linear approximations to utility or value functions (see, for example, Jacquet-Lagreze and Siskos 1982; Shakun 1988). Influenced by the French school are the PROMETHEE methods of Brans, Mareschal and Vincke (1984). In addition, a number of other methods such as MAPPAC and PRAGMA by Matarazzo (1988) have been proposed for solving multicriteria discrete alternative problems. All involving preference modelling, the procedures, in Europe, go under the name of multiple criteria decision aids (Vincke 1986).

A large body of multiple criteria research also exists in the Soviet literature. As discussed in Ozernoy (1988) and Lieberman (1991), much of this literature is available only in Russian. While most of the early Soviet research is MCDM-related, there has been a rapid growth in discrete alternative methods and MAUT-related topics in recent years. Important contributions include the ϵ-efficiency research of Salukvadze (1975) and Podinovski and Noghin (1982); methods for solving nonlinear multiple criteria optimization problems by discrete representation (Sobol and Statnikov 1981); the incorporation of Soviet behavioral and psychological research into the construction of MCDSSs (Larichev 1987); and the generalized reachable set ideas of Lotov (1984). With the new openness between East and West, there are good opportunities to merge the two literatures to achieve new and improved MCDM/MAUT procedures.

The Analytic Hierarchy Process (AHP) (Saaty 1980, 1986) is sometimes classified as a MAUT approach. It involves an importance-ratio assessment procedure and uses a hierarchy to establish preferences and orderings. A linear model is then derived and used to rank alternatives. Sensitivity analysis is possible by changing weights. The method is embodied in software known as Expert Choice (Forman, Saaty, Selly and Waldron 1983). Golden, Wasil and Levy (1989) also point out that the AHP has multiple criteria optimization applicabilities. An example of a bridge that can be built between MAUT and MCDM is given in Stam and Kuula (1991). In this paper, multicriteria optimization techniques are used as screening devices to produce small groups of solutions, and the AHP is used to determine which solution in the group is the most preferred at each iteration.

3. International Perspective

A fascinating characteristic of MCDM and MAUT is its international scope. As suggested above, the fields are not solely a product of North American and Western European culture. They have long been of interest to the socialist economies of Eastern Europe and Third World nations because of their applicability to centralized planning.

The International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria has played an important role in developing, applying, and promoting MCDM and MAUT. In its commitment to complex nonpolitical problems of global concern such as in water resources, forestry, energy planning, population, and environmental ecology, IIASA has been a major supporter of MCDM and MAUT as essential methodologies for analyzing such problems. Through its sponsorship of conferences and networking, IIASA has stimulated an east–west cross-fertilization of ideas.
The international and interdisciplinary flavors of MCDM and MAUT, as well as the pervasiveness of multiple criteria in decision problems, have led to explosive growth during the 1980s. A popular newsletter, *MCDM WorldScan*, is distributed to over 1000 readers in over 55 countries, and there are other newsletters in circulation. *The Journal of Multi-Criteria Decision Analysis* begins publication in 1992. Numerous international conferences on different continents have been sponsored by the International Society on Multiple Criteria Decision Making; IIASA; the Society for Judgment and Decision Making; the Organization for Subjective Probability, Utility and Decision Making; ESIGMA (the European Summer Institute Group on Multicriteria Analysis); the European Working Group on Multiple Criteria Decision Aid; and the Chinese Special Interest Group on Multiple Criteria Decision Making.

4. Descriptions

Our fields of concern normally presume a single decision maker who is to choose among a number of alternatives that he or she evaluates on the basis of two or more criteria or attributes. The alternatives can involve risks and uncertainties; they may require sequential actions at different times; and the set of alternatives might be either finite or infinite. A finite set is typified by the available houses for sale in the buying of a residence. An infinite set arises in the design of a piece of electronic equipment involving continuous parameters subject to constraints that limit the feasible region. In the simplest cases, the decision maker acts to maximize a utility or value function that depends on the criteria or attributes.

In its most basic form, MCDM assumes that a decision maker is to choose among a set of alternatives whose objective function values or attributes are known with certainty. Many problems in MCDM are formulated as multiple objective linear, integer, or nonlinear mathematical programming problems, and many of the procedures proposed for their solution are interactive.

MAUT is sometimes subsumed under MCDM, but is usually treated separately when risks or uncertainties have a significant role in the definition and assessment of alternatives. It focuses on the structure of multicriteria or multiattribute alternatives, usually in the presence of risk or uncertainty, and on methodologies for assessing individuals’ values and subjective probabilities. MAUT embraces both a large body of mathematical theory for utility models and a wide range of practical assessment techniques that pay attention to limited abilities of assessors. Information obtained from assessment usually feeds into the parent problem to rank alternatives, make a choice, or otherwise clarify a situation for the decision maker. Sensitivity analysis is often involved in the assessment and choice processes.

The role of the value function is a demarcating feature between MAUT and MCDM. Generally, if the value function is *explicit*, the method is considered in the MAUT category; if the value function is *implicit* (assumed to exist but is otherwise unknown) or no such function is assumed to exist, the method is usually classified under MCDM. In most MCDM methods, the user need not be aware that there is a value function.

5. Areas for Future Research

The past few decades have been exciting ones for the development of decision theory and decision analysis. With MAUT about five years older than MCDM, many contributors to the fields can remember the time when the MCDM and MAUT acronyms were unrecognized by the general operations research/management science (OR/MS) population. Today, the fields are an established part of OR/MS. For instance, almost all new introductory textbooks on OR/MS now contain at least one chapter on MCDM and MAUT (Buffa and Dyer 1981; Hillier and Lieberman 1986; Cook and Russell 1989; Winston
1991). While the past has been exciting for MCDM/MAUT, the future appears to be equally promising. Specific areas for new research in MCDM/MAUT include the following. We say more about some of these areas later.


2. Sensitivity analysis and the incorporation of vague or imprecise judgments of preferences and/or probabilities in multiattribute situations and decisions under uncertainty in which states are multidimensional. This is presently a very active area of research. See §B and §C for references.

3. The usefulness of eclectic approaches that pick and choose among existing theory and practice to improve multicriterion decision procedures. See, for example, Lotfi, Stewart and Zionts (1990).

4. Development of improved interactive software for multicriterion decision support systems, taking into account the findings of psychological research about biases and heuristics (Kahneman, Slovic and Tversky 1982; Hogarth 1987, 1990; Dawes 1988).

5. Methods of inferring preferences among complex outcomes or alternatives on the basis of partial information that can realistically be obtained from decision makers. Examples in this area include Korhonen, Wallenius and Zionts (1984), Prasad, Karwan and Zionts (1990), and Fishburn (1992).

6. Improvements in linear vector optimization that would enable the construction of an MOLP (multiple objective linear programming) solver that would subsume conventional LP solvers in the special case when the number of objectives is one. See Armand (1991) for recent results in linear vector optimization.

7. Consolidation in interactive multiple objective programming. The endeavor here is to include groups of interactive procedures that have implementation similarities in a common algorithmic product (Gardiner and Steuer 1991). This would then permit procedure-switching which recognizes that the procedures most useful early in the decision process might be different from procedures most useful late in the decision process (Buchanan and Daellenbach 1987).

A. Decision Support Aspects of MCDM

MCDM research in the 1970s focused on the theoretical foundations of multiple objective mathematical programming and on procedures and algorithms for solving multiple objective mathematical programming problems. The theoretical convergence of the procedures was often seen to be as important as the functioning of the procedures themselves.

During the 1980s, emphasis shifted toward the implementation of MCDM models on computers with the aid of decision support systems (DSS). Ginzberg and Stohr (1982) characterize a DSS as “a computer-based information system used to support decision-making activities in situations where it is not possible or desirable to have an automated system perform the entire decision process.” A multiple criteria decision support system (MCDDS) is simply a DSS that helps to implement MCDM or MAUT models. An early example is Dyer (1973). Characteristics of MCDDSs that are often absent from other types of decision support systems include analyses of multiple criteria, involvement of MCDM methods, and the integration of user input in the modelling processes. See, for example, Jelassi, Jarke and Stohr (1985).

Recent research has focused on the user interface, on finding good instead of “optimal” solutions, and on supporting the entire decision-making process from problem structuring through solution implementation. We view this as a healthy trend. One documented application is the visual Pareto Race interactive system described in Korhonen and Wallenius (1988). Their system and others incorporate procedures and models as integral components of decision support systems, and problem structuring and formulation receive the attention they deserve.
Other simple ideas have been particularly effective. One of these, embodied in an approach of Lotfi, Stewart and Zionts (1990), involves adjusting aspiration levels and obtaining rapid feedback on the reasonableness of the demands. Another is the approach of Read and Gear (1989) which uses rapid information exchange in negotiation problems.

B. Behavioral Aspects

Psychologists and behavioral decision theorists have studied human decision making in great detail. Since the late 1960s, Amos Tversky, Hillel Einhorn and others have developed new theories and paradigms to explain decision behavior. See, for example, Schoemaker (1980), Kahneman, Slovic and Tversky (1982), Hogarth (1987, 1990) and Dawes (1988). A popular approach is prospect theory (Kahneman and Tversky 1979), which expresses outcomes as positive or negative deviations from a reference point. Its marginal value functions are typically S-shaped, concave above the reference outcome and convex below it. An enhanced version of prospect theory and a related theory based on comparisons of gains and losses are given in Tversky and Kahneman (1990) and Luce and Fishburn (1991).

Thus far, behavioral research has had little impact on multiple criteria decision making, an exception being theoretical generalizations of classical decision theory assumptions of von Neumann and Morgenstern (1944) and Savage (1954) discussed in Keeney and Raiffa (1976), Fishburn (1988) and Wakker (1989). Too few researchers in multiple objective mathematical programming and systems engineering have critically examined the assumptions postulated about human behavior by the classical theories.

The question is not whether we should pay more attention to the behavioral realities of decision making, but rather how we can best account for those realities in decision analyses. In other words, how should we incorporate the existing behavioral and psychological knowledge in designing systems? A valuable general reference is von Winterfeldt and Edwards (1986).

A specific finding reported in Korhonen, Moskowitz and Wallenius (1990) indicates that the decision “path” may affect the final choice. Such a result is perhaps consistent with the cognitive equilibrium ideas of Zeleny (1989) in which a solution is achieved only after adjustments have been made to bring the decision maker’s aspirations and understanding of the problem into harmony. It might therefore be important to look at the problem from different perspectives that use multiple representations, as in Dyer and Miles (1977) and von Winterfeldt (1982). Other lessons tell us that behavioral convergence is far more important than mathematical convergence, and that careful consideration must be given to the choice and display of information during the course of decision making.

C. Robustness Considerations

Precision in problem formulation, and in knowing the preferences and subjective probabilities of the decision maker, has often been assumed in decision theory. During the 1980s this has increasingly been challenged and attempts have been made to relax it. The question of precision ties in with our consideration of sensitivity analysis and extension of the concepts of utility and probability discussed earlier. Areas for imprecision accommodation include the following:

1. Problem formulation: Some recent contributions do not assume a fixed set of decision alternatives, but allow it to be expanded. For example see Korhonen, Moskowitz and Wallenius (1986). The application of fuzzy set logic provides another approach to imprecise formulation (Hannan 1981; Carlsson 1982; Sakawa 1983).

2. Preferences: Some recently proposed multiple criteria decision support systems allow decision makers’ preferences to be imprecise, and even intransitive. Recent theoretical
work that challenges transitivity in multiattribute settings is presented in Gehrlein (1990) and Fishburn (1991).

3. Probabilities: Vagueness in probability judgments has long been a topic of concern and sometimes appears under the heading of *ambiguity* (Einhorn and Hogarth 1986; Hazen 1989; Heath and Tversky 1991). An example of robust interactive decision analysis that allows imprecision in probability assessments is described in Moskowitz, Wong and Chu (1989). When relaxations of these types are taken into account, model robustness becomes an important consideration. New methods are needed to deal with imprecise aspects and the types of solutions they generate.

D. The Role of Heuristics

Heuristics are proving more and more valuable in many areas of management science and operations research. An extensive survey by Zanakis, Evans and Vazacopoulos (1989) of heuristic methods and their applications to management problems identified more than 400 articles in 37 journals over the last 16 years. The appeal of heuristic methods stems from their ability to quickly generate near-optimal solutions to difficult problems. Although the main arena of application of heuristics is in combinatorial problems and job shop scheduling, heuristics are also proving valuable in MCDM/MAUT and related areas. Examples for MCDM include the AIM approach of Lotfi, Stewart and Zionts (1990), Kornbluth’s (1986) multiple objective dynamic programming procedure, and interactive approaches for multicriteria integer programming such as Gabbani and Magazine (1986) and Ramesh, Karwan and Zionts (1986).

Heuristics can also be used to simplify choices, identify good starting solutions for different procedures, and partition problems into subproblems. It is sometimes worthwhile relaxing or restricting the set of alternatives to simplify solvability, but there are limitations to such procedures. The relationship of heuristics to issues of flexibility and robustness also merits research.

6. Implementation Considerations

Although the technology of large computers continues its rapid advance, it seems likely that most implementations will occur at the microcomputer level. Moreover, large problems that need the power of mainframes can often use microcomputers to prepare data and to interface with their larger cousins. Recent computer advances that impact decision making include computer graphics, both in terms of graphical representations and colors, and advanced interfaces that may involve multiple screens.

Recent developments in personal computers and software packages have shifted attention towards the use of computer graphics to visualize multiple criteria decision problems and decision alternatives. Although the problem of representing multivariate data in a visual format is far from new, it is a relatively novel idea to develop good visuals for MCDM and MAUT. The problem is how best to visualize or graphically represent multiple criteria decision problems and alternatives. It might be best to start with aggregate data and then “zoom” down to detailed data as desired, but the entire process seems wide open to further exploration.

A. Software Considerations

Software should be easy to use, and for enhanced utility should accommodate a spreadsheet format. Several spreadsheet optimization systems have been developed during the 1980s to support decision-making processes, and others are being developed. In a typical application, the model builder expresses the problem in the language of a spreadsheet, such as Lotus 1-2-3, rather than in algebraic notation. Another example is IFPS/Optimum, based upon the IFPS planning system. These optimizers are opening up new
horizons for applications. Additional details are given in Roy, Lasdon and Plane (1989). Because spreadsheet-based systems express models in a popular and widely understood format, further emphasis on their use in MCDM is desirable.

B. Applications

There is a continuing need for good documented applications. Some good applications have been published: see for example the bibliography in White (1990) and the collections of applications in Stadler (1988) and Eschenauer, Koski and Osyczka (1990). But the need for published case histories remains strong. Incentives should be provided for companies to report their experiences, and for journals and professional societies to hold competitions for publications.

There is evidence, at least in Finland, that the public sector is an increasingly interested user of MCDM/MAUT models. Because most public sector problems involve multiple conflicting objectives, whether in public health care systems, environmental policy, water resources, energy, or macroeconomic planning, the opportunities for MCDM applications are unlimited.

A quotation from the Welcoming Address of the honorable Mr. Pertti Salolainen, Finnish Minister for Foreign Trade, at the IIASA International Workshop on Multiple Criteria Decision Support in Helsinki, August 7, 1989 is insightful: “The Finnish Government has applied multiple objective models and decision support systems in the past to help improve efficiency of operations or obtain a better understanding of complex decision processes. An example of such an application is a study performed in cooperation with the National Board of Economic Defense to help prepare contingency plans for various emergency management situations, such as nuclear power plant accidents, trade embargoes, and international conflicts. With the help of these models Finland is now better prepared to face various emergency management situations. In general, it is my opinion that the public sector in Finland has maintained a belief in the usefulness of applying analytical decision tools in problem solving in one form or the other.” How can we learn from the experience in Finland? By trying to work with people and organizations having MCDM/MAUT problems, and helping them to solve their problems.

7. Conclusions

We still need simple, understandable, and usable approaches for solving MCDM and MAUT problems. Such approaches will undoubtedly be built around decision support systems. The decision support systems that survive and are widely used will have to be user friendly and have other good qualities. Software that has the attributes of easy-to-use spreadsheets is most desirable.

Extensive research has been done in the areas of multiple criteria decision making, multiattribute utility theory, and related decision support systems, but a vast amount of additional work remains for the years ahead. We hope that this article will provide useful directions for that work.¹

¹ This paper evolved from a panel discussion at the ORSA/TIMS Joint National Meeting in New York City, October 16, 1989.

References


