Trends in Multiple Criteria Decision Analysis

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Introduction

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1 Introduction

When 5 years ago we edited the book "Multiple Criteria Decision Analysis: State of the Art Surveys" with 24 chapters written by 49 international leading experts, we believed that the book would cover the research field for several years. But over the last 5 years Multiple Criteria Decision Analysis (MCDA) has received an increasing interest and has experienced a development faster than we expected. Thus, what looked like a comprehensive collection of state-of-the-art surveys appears clearly partial and incomplete a few years later. New approaches and new methodologies have been developed which even contribute to change the paradigm of MCDA. A researcher who does not take into account the new contributed risks to be disconnected from the main trends of the discipline and to have a misleading conception of it. These thoughts convinced us to explore the map of the new trends in MCDA in order to recognize the most promising new contributions. This book comprises 13 chapters, once again written by leading international experts, that summarize trends in MCDA that were not covered in our previous book and that describe the development of rapidly evolving sub-fields of MCDA.

Po-Lung Yu and Yen-Chu Chen present the theory of dynamic multiple criteria decision analysis, habitual domains, and competence set analysis. In real life, most decisions are dynamic with multiple criteria. Even though most of the MCDA literature assumes that the parameters involved in decision problems – such as the set of alternatives, the set of criteria, the preference structures of the decision makers – are more or less fixed and steady, in reality – for most nontrivial decision problems – these parameters can change dynamically. In fact, satisfactory solutions are obtained only when those parameters are properly structured. To analyze the decision process in a dynamic context the concepts of habitual domain and competence set are of fundamental importance. A habitual domain is the set of ideas and concepts which we encode and store in our brain, gradually stabilized over a period of time. The competence set is a collection of ideas, knowledge, resources, skills, and effort for the effective solution of a decision problem. Competence set analysis and habitual domain theory suggest how to expand and enrich our competence

set and how to maximize the value of our competence set. In this perspective, any decision problem can be dealt with by restructuring its elements and environmental facets in order to gain a broader and richer perception permitting to derive effective solutions.

Andrzej P. Wierzbicki discusses the need for and possible methods of objective ranking after observing that the classical approach in decision analysis and multiple criteria theory concentrates on subjective ranking. However, in many practical situations, the decision maker might not want to use personal preferences, but prefers to have some objective ranking. One reason for objectivity is that decisions of a given class might influence other people, e.g., some decision situations dominating in technology creation, such as constructing a safe bridge or a safe car. Thus, technologists stress objectivity but real managers also know well that there are many managerial situations where stressing objectivity is necessary. Therefore, even if it can be agreed that an absolute objectivity is not attainable, it is reasonable to treat the concept of objectivity as a useful ideal worth striving for, looking for objective ranking interpreted as an approach to ranking that is as objective as possible. Between many possible multiple criteria approaches, the reference point approach (already introduced in the literature to deal with interactive multiple criteria optimization) is mentioned as the best suited methodology for rational objective ranking, because reference levels needed in this approach can be established to some extent objectively – statistically from the given data set.

Jonathan Barzilai in his provocative chapter discusses preference function modelling, i.e., the mathematical foundations of decision theory. He formulates the conditions that must be satisfied for the mathematical operations of linear algebra and calculus to be applicable and claims that the mathematical foundations of decision theory and related theories depend on these conditions, which have not been correctly identified in the classical literature. He argues that Operations Research and Decision Analysis Societies should act to correct fundamental errors in the mathematical foundations of measurement theory, utility theory, game theory, mathematical economics, decision theory, mathematical psychology, and related disciplines. Consequences of this approach to some MCDA methodologies such as AHP or value theory are also discussed.

Hassene Aissi and Bernard Roy discuss robustness in MCDA. The term *robust* refers to a capacity for withstanding "vague approximations" and/or "zones of ignorance" in order to prevent undesirable impacts. Robustness concerns are related to the observation that an action is made, executed, and judged in a real-life context that may not correspond exactly to the model on which the decision analysis is based. The gap between formal representation and real-life context originates frailty points against which the robustness concern attempts to protect. Robustness concerns can be dealt with using approaches involving a single robustness criterion, completing a preference system that has been defined previously, or using several criteria. Robustness can be considered other than by using one or several criteria to compare the solutions in approaches that involve one or several properties designed to characterize the robust solution or to draw robust conclusions. The considerations developed

in this chapter show that the use of multiple criteria for apprehending robustness in MCDA is a field of research open to future development, both theoretically and practically.

Bernard De Baets and János Fodor consider preferences expressed in a gradual way. The key concept is that the application of two-valued (yes or-no) preferences, regardless of their sound mathematical theory, is not satisfactory in everyday situations. Therefore, it is desirable to consider a degree of preference. There are two main frameworks in which gradual preferences can be modeled: fuzzy preferences, which are a generalization of Boolean (2-valued) preference structures, and reciprocal preferences, also known as probabilistic relations, which are generalization of the three-valued representation of complete Boolean preference relations. The authors consider both frameworks. Since the whole exposition makes extensive use of (logical) connectives, such as conjunctors, quasi-copulas and copulas, the authors provide an appropriate introduction on the topic.

Radko Mesiar and Lucia Vavríková present fuzzy set and fuzzy logic-based methods for MCDA. Alternatives are evaluated with respect to each criterion on a scale between 0 and 1, which can be seen as membership function of fuzzy sets. Therefore, alternatives can be seen as multidimensional fuzzy evaluations that have to be ordered according to the decision maker's preferences. This chapter considers several methodologies developed within fuzzy set theory to obtain this preference order. After discussion of integral-based utility functions, a transformation of vectors of fuzzy scores x into fuzzy quantity $U(x)$ is presented. Orderings on fuzzy quantities induce orderings on alternatives. Special attention is paid to defuzzification-based orderings, in particular, the mean of maxima method. Moreover, a fuzzy logic-based construction method to build complete preference structures over the set of alternatives is given.

Wassila Ouerdane, Nicolas Maudet, and Alexis Tsoukiàs discuss argumentation theory in MCDA. The main idea is that decision support can be seen as an activity aiming to construct arguments through which a decision maker will convince first herself and then other actors involved in a problem situation that "that action" is the best one. In this context the authors introduce argumentation theory (in an Artificial Intelligence oriented perspective) and review a number of approaches that indeed use argumentative techniques to support decision making, with a specific emphasis on their application to MCDA.

Valerie Belton and Theodor Stewart introduce problem structuring methods (PSM) in MCDA providing an overview of current thinking and practice with regard to PSM for MCDA. Much of the literature on MCDA focuses on methods of analysis that take a well-structured problem as a starting point with a well-defined set of alternatives from which a decision has to be made and a coherent set of criteria against which the alternatives are to be evaluated. It is an erroneous impression that arriving at this point is a relatively trivial task, while in reality this is not so simple even when the decision makers believe to have a clear understanding of the problem. Thus, PSM provides a rich representation of a problematic situation in order to enable effective multicriteria analysis or to conceptualize a decision, which is initially simplistically presented, in order for the multicriteria problem to be appropriately

framed. The chapter outlines the key literature, which explores and offers suggestions on how this task might be approached in practice, reviewing several suggested approaches and presenting a selection of case studies.

Salvatore Greco, Roman Słowiński, José Rui Figueira, and Vincent Mousseau present robust ordinal regression. Within the disaggregation–aggregation approach, ordinal regression aims at inducing parameters of a preference model, for example, parameters of a value function, which represent some holistic preference comparisons of alternatives given by the decision maker. Usually, from among many sets of parameters of a preference model representing the preference information given by the DM, only one specific set is selected and used to work out a recommendation. For example, while there exist many value functions representing the holistic preference information given by the DM, only one value function is typically used to recommend the best choice, sorting, or ranking of alternatives. Since the selection of one from among many sets of parameters of the preference model compatible with the preference information given by the DM is rather arbitrary, robust ordinal regression proposes taking into account all the sets of parameters of the preference model compatible with the preference information, in order to give a recommendation in terms of necessary and possible consequences of applying all the compatible preference models on the considered set of alternatives. For example, the necessary weak preference relation holds for any two alternatives a and b if and only if all compatible value functions give to a a value greater than or equal to the value provided to b, and the possible weak preference relation holds for this pair if and only if at least one compatible value function gives to a a value greater than or equal to the value given to b. This approach can be applied to many multiple criteria decision models such as multiple attribute utility theory, fuzzy integral modeling interaction between criteria, and outranking models. Moreover, it can be applied to interactive multiple objective optimization and can be used within an evolutionary multiple objective optimization methodology to take into account preferences of the decision maker. Finally, robust ordinal regression is very useful in group decisions where it permits to detect zones of consensus for decision makers.

Risto Lahdelma and Pekka Salminen present Stochastic Multicriteria Acceptability Analysis (SMAA). SMAA is a family of methods for aiding multicriteria group decision making in problems with uncertain, imprecise, or partially missing information. SMAA is based on simulating different value combinations for uncertain parameters, and computing statistics about how the alternatives are evaluated. Depending on the problem setting, this can mean computing how often each alternative becomes most preferred, how often it receives a particular rank, or obtains a particular classification. Moreover, SMAA proposes inverse weight space analysis, using simulation with randomized weights in order to reveal what kind of weights make each alternative solution most preferred. After discussing several variants of SMAA the authors describe several real-life applications.

D. Marc Kilgour, Ye Chen, and Keith W. Hipel discuss multiple criteria approaches to Group Decision and Negotiation (GDN). After explaining group decision and negotiation, and the differences between them, the applicability of MCDA techniques to problems of group decision and negotiation is discussed. Application

of MCDA to GDN is problematic because – as shown by the well-known Condorcet paradox and by Arrow's theorem on collective choices – collective preferences may not exist. While ideas and techniques from MCDA are directly applicable to GDN only rarely, it is clear that many successful systems for the support of negotiators, or the support of group decisions, have borrowed and adapted ideas and techniques from MCDA. The paper presents a review of systems for Group Decision Support and Negotiation Support, then highlights the contributions of MCDA techniques and some suggestions for worthwhile future contributions from MCDA are put forward.

Kalyanmoy Deb presents recent developments in Evolutionary Multi-objective Optimization (EMO). EMO deals with multiobjective optimization using algorithms inspired by natural evolution mechanisms using a population-based approach in which more than one solution participates in an iteration and evolves a new population of solutions at each iteration. This approach is a growing field of research with many applications in several fields. The author discusses the principles of EMO through an illustration of one specific algorithm (NSGA-II) and an application to an interesting real-world bi-objective optimization problem. Thereafter, he provides a list of recent research and application developments of EMO to paint a picture of some salient advancements in EMO research such as hybrids of EMO algorithms and mathematical optimization or multiple criterion decision-making procedures, handling of a large number of objectives, handling of uncertainties in decision variables and parameters, solution of different problem-solving tasks by converting them into multi-objective problems, runtime analysis of EMO algorithms, and others.

Jacek Malczewski introduces MCDA and Geographic Information Systems (GIS). Spatial decision problems typically involve sets of decision alternatives, of multiple, conflicting, and incommensurate evaluation criteria, and, very often, of individuals (decision makers, managers, stakeholders, interest groups). The critical aspect of spatial decision analysis is that it involves evaluation of the spatially defined decision alternative and the decision maker's preferences. This implies that the results of the analysis depend not only on the geographic pattern of decision alternatives, but also on the value judgments involved in the decision-making process. Accordingly, many spatial decision problems give rise to GIS-MCDA, being a process that combines and transforms geographic data (input maps) and the decision maker's preferences into a resultant decision (output map). The major advantage of incorporating MCDA into GIS is that a decision maker can introduce value judgments (i.e., preferences with respect to decision criteria and/or alternatives) into GIS-based decision making enhancing a decision maker's confidence in the likely outcomes of adopting a specific strategy relative to his/her values. Thus, GIS-MCDA helps decision makers to understand the results of GIS-based decision-making procedures, permitting the use of the results in a systematic and defensible way to develop policy recommendations.

The spectrum of arguments, topics, methodologies, and approaches presented in the chapters of this book is surely very large and quite heterogeneous. Indeed MCDA is developing in several directions that probably in the near future would need to be reorganized in a more systematic theoretical scheme. We know that not

all new proposals currently discussed in the field are represented in the book and we are sure that new methodologies will appear in the next years. However, we believe that the book represents the main recent ideas in the field and that, together with the above quoted book "Multiple Criteria Decision Analysis – State of the Art Surveys," it gives sufficient resources for an outline of the field of MCDA permitting to understand the most important and characterizing debates in the area being wholly aware of their origins and of their implications.

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