Multicriteria Decision Analysis in Group Decision Processes

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Introduction

Group decision making is involved in the vast majority of consequential decisions where there is a need to choose which one out of many of alternative courses of action should be pursued, in view of the multiple objectives that are seen as important by the group members (see, e.g., Belton and Stewart, 2002; Figueira et al., 2005; French, 1986; French et al., 2009; Keeney and Kirkwood, 1975). Even if the decision is ultimately taken by a single individual, the decision may affect several stakeholders whose interests need to be recognized. In these situations, too, it may be instructive to organize consultation processes where the stakeholders' preferences are systematically charted, with the aim of informing the decision maker how the alternatives are perceived by the stakeholders (Geldermann et al., 2009; Hämäläinen et al., 2001).

The literature on multicriteria decision analysis (MCDA) offers numerous methods which help decision makers address problems characterized by multiple objectives (for textbooks and surveys, see, e.g., Belton and Stewart, 2002; Figueira et al., 2005; French, 1986; Wallenius et al., 2008). Fundamentally, these objectives represent the subjective *values* that are important in the decision making situation. The articulation of these values in terms of corresponding objectives can be useful for many reasons: for instance, it fosters the identification, elaboration and prioritization of alternatives that contribute to the realization of values (Keeney, 1992). For example, the value of *safety* may suggest objectives such as *reducing the number of accidents*, *reducing the severity of injuries in accidents*, or *providing faster access to first-aid services*, which can be examined further to derive suggestions for alternative courses of actions for the improvement of safety. Indeed, the systematic concretization of objectives in terms of corresponding evaluation criteria and attendant measurement scales offers an operational approach for assessing how the alternatives contribute to the decision objectives and thus the realization of values. MCDA methods thus offer systematic frameworks that help synthesize both subjective and objective information, in order to generate well-founded guidance for decision making.

From a theoretical perspective, many MCDA methods build on normative theories of decision making that characterize what choices a decision maker would make among alternatives, if his or her preferences comply with stated rationality axioms (see, e.g., Keeney and Kirkwood, 1975; Von Winterfeldt and Edwards, 1986). Extensions of these theories into group settings have contributed to the development of MCDA methods which are capable of admitting and synthesizing information about the group members' preferences and which can therefore offer insights into what alternatives are preferred to others by the participating individuals or the group as a whole. Such insights enable *learning processes* which can be an important – if not the most important – motivation for MCDA-based decision modeling: for instance, these processes may help the stakeholders to learn about their own preferences or about each others' perspectives into the shared decision problem (see, e.g., Gregory et al., 2001).

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In this chapter, we consider decision settings where a group seeks to collaborate, with the aim of identifying the most preferred one out of many alternatives, based on an explicit articulation of decision objectives, corresponding evaluation criteria and the appraisal of alternatives with regard to these criteria. The members of this group can be either *decision makers* or representatives of *stakeholders* who are impacted by the decision and have consequent interests in the decision outcome.

We assume that the number of decision alternatives is not too large so that all alternatives can be evaluated with regard to all the decision criteria. If this is not the case, suitable screening approaches can be applied to reduce the set of initial alternatives. The number of groups members involved in the decision support process may vary: for example, if web-based approaches are employed, even hundreds of group members can be consulted (see, e.g., Hämäläinen, 2003). We also assume that there are multiple criteria and that these are explicitly addressed. The many variants of voting procedures discussed in the literature on social choice are therefore beyond the scope of this paper (see Arrow and Raynaud, 1986 for a seminal reference and see also the Chapter by Nurmi, in this volume). Nor do we cover multicriteria agency models (Vetschera, 2000), game theoretic approaches (see also the chapter by Kibris, this volume), conflict analysis methods (see also the chapter by Kilgour and Hipel, this volume) or bargaining models where the group members (or agents) pursue different objectives (Ehtamo and Hämätäinen, 2001; Mármol et al., 2007).

MCDA Methods

Although MCDA methods differ in their details (e.g., Belton and Stewart, 2002; French et al., 2009; Wallenius et al., 2008), they are often deployed by adopting rather similar decision support processes. At a high level of aggregation, these processes often consist of partly overlapping and iterative phases:

1. *Clarification of the decision context and the identification of group members*: An important initial phase is the *scoping* of the decision support process. Here, it is necessary to clarify what the decision is really about, how the group members are identified and engaged, and in what role they will participate in the process. They can take part, for instance, as decision makers, sources of expertise, or representatives of their respective stakeholder groups (cf. Belton and Pictet, 1997). Also, even if in high-level decision making the actual decision makers may not be able to devote much time to the process, it is often advantageous to include some decision makers in the group, because this engages them into an intensive learning process, which is likely to expedite the uptake and implementation of decision recommendations.
2. *Explication of decision objectives*: Starting from the *values* that are seen as important by the group members in the decision making situation, the relevant decision objectives are elaborated and transformed into corresponding evaluation criteria and associated measurement scales with the help of which the attainment of these objectives can be assessed. This phase can be complemented through in-depth interviews and questionnaires. It also often benefits from the guidance that a skilled neutral facilitator can provide.
3. *Generation of decision alternatives*: A sufficiently representative and manageable set of alternatives is generated, possibly by applying suitable creativity techniques (Keeney, 1992; Sternberg, 1999) when considering how the decision objectives could be achieved through alternative courses of action. This phase is important, because the development of eventual recommendations is strongly guided by the alternatives that are included in the analysis at the outset. Thus, the process may be compromised by "errors of omission" if good alternatives are not included in the analysis.
4. *Elicitation of preferences*: The group members are engaged in an elicitation process where subjective preference statements are solicited about (i) how important the different evaluation criteria are relative to each other, and (ii) how much value the group members associate with the alternatives' performance levels on criterion-specific measurement scales. Here, the different group members may offer different responses, depending on their preferences.
5. *Evaluation of decision alternatives*: All alternatives are measured with regard to every decision criterion using a related measurement scale. These evaluations can be based, among other things, on the use of empirical data, subjective judgments by external experts or by the group members themselves.

6. *Synthesis and communication of decision recommendations*: MCDA methods are employed in order to derive decision recommendations by combining group members' preferences with the alternatives' criterion-specific evaluations. A careful examination of the resulting recommendations, in conjunction with the learning process of MCDA analysis, may suggest a respecification of alternatives or even objectives. In this case, it may be appropriate to repeat some of the above phases.

At times, the third and fourth phases can be carried out in the reverse order so that preference statements about the relative importance of attributes are elicited *before* alternatives are generated. This notwithstanding, we believe that it is usually advisable to first develop an initial set of alternatives, because the process of generating alternatives may give the group members an improved understanding of the decision context. That is, the decision process may shape the group members' preferences which can be elicited more reliably after some alternatives are explicitly defined.

The fifth phase of evaluating alternatives often builds on information from many sources. It may therefore be best carried out in a decentralized mode where the participants are invited to evaluate alternatives with regard to those criteria they are knowledgeable about. In large scale decision support processes that involve many stakeholder groups, analogous phases of preference elicitation can also be supported with the help of Internet-based decision support tools (Hämäläinen, 2003).

The close involvement of group members will be particularly crucial in the first and last phases where the focus is on problem structuring, elaboration of objectives and the development of decision recommendations. Here, an external facilitator often has an important role in ensuring that the group members' preferences are properly charted and that each group member has a chance of voicing his or her concerns. A facilitator also has a critical role in ensuring that (i) methodologies are employed correctly, taking into account the pitfalls of human decision biases (Hämäläinen and Alaja, 2008; Regan et al., 2006), (ii) the group members are aware of the assumptions of the decision model, and (iii) the results of the decision model are fully understood in relation to the inputs.

The delineation of the above phases in MCDA-assisted decision support processes does not emphasize the broader impacts of these processes, such as the collective learning that takes place as the group members put forth their arguments and their perspectives evolve. For example, the examination of tentative results may lead to the recognition of further objectives, or suggest alternatives which were not initially considered. As a result, it may be pertinent to adopt iterative processes which provide possibilities for revisiting the earlier phases. Especially in new decision contexts – where it may be difficult to recognize all the relevant criteria or alternatives at the outset – it may be useful to generate tentative initial results for learning purposes before proceeding to the later rounds.

We next illustrate approaches to preference elicitation and synthesis by presenting the main features of probably the two widely used MCDA methodologies. Here, we note that there exist numerous other MCDA approaches as well, such as those based on goal programming (Fan et al., 2006) and outranking relations (Roy, 1996).

Multiattribute Value and Utility Theory

Multiattribute Value Theory (MAVT) is a methodological framework which offers prescriptive decision recommendations for making choices among alternatives $x = (x_1, \ldots, x_n)$ which have consequences x_i with regard to n attributes (Belton and Stewart, 2002; French, 1986; Keeney and Raiffa, 1976) MAVT is based on a set of axioms that characterize rational decision making. For example, it is postulated that a rational decision maker has complete preferences, meaning that for any two multi-attribute alternatives x and y, the decision maker either finds that these alternatives are equally preferred, or that one is preferred over the other. Moreover, the preferences are assumed to be transitive, meaning that if the decision maker prefers alternative x over y and alternative y over z, then x is logically preferred over z.

Mutual preferential independence is a key axiom in MAVT (Keeney and Raiffa, 1976). Specifically, this axiom holds if the decision maker's preferences for alternatives which have different consequences on some attributes and similar consequences on some other attributes do *not* change if the alternatives' similar consequences are changed. If this axiom holds along with other, less restrictive axioms, there exists an additive multi-attribute value function, defined on the alternatives' consequences, such that alternative x is preferred to y if and only if

$$x \succeq y \iff V(x) = \sum_i v_i(x_i) \geq \sum_i v_i(y_i) = V(y). \tag{1}$$

The existence of the value function has been proved using a topological approach (Debreu, 1960) and an algebraic approach (Krantz et al., 1971). The value function is unique up to positive affine transformations. Thus, the preference relation that it induces on the alternatives does not change if the values are multiplied by a positive constant $\alpha > 0$ or if a constant β is added to the overall values of all alternatives. Due to this property, the MAVT function in (1) can be written in the customary form

$$V(x) = \sum w_i v_i(x_i), \tag{2}$$

where the scores $v_i(\cdot)$ are typically normalized onto the [0,1] range so that the score of the least preferred alternatives on a given attribute is zero while that of the most preferred alternative is one. Furthermore, the w_i denote the attribute weights, which reflect the decision maker's preferences for the improvements obtained by *changing* consequences from the least preferred attribute level to the most preferred attribute level. These weights are customarily normalized so that they add up to one, i.e., $\sum_i w_i = 1$.

Keeney and Raiffa (1976) extend the MAVT framework into group decision making settings where the groups' aggregate value depends on the values that are attained by the individual group members. Specifically, they show that if the requisite axioms hold, the group's aggregate value function can be expressed as

$$V(x) = \sum_k W_k \sum w_{ki} v_{ki}(x_i), \tag{3}$$

where W_k denotes the importance weight of the k-th decision maker and the latter sum represents the value that alternative x will give to her.

When using the MAVT framework in group decision support, the parameters of the representation (1) or (3) are first estimated whereafter the alternatives' overall values are used for deriving decision recommendations. However, it is pertinent to check that the underpinning axioms hold and to elicit score and weight parameters carefully, with the aim of mitigating the possibility of biases.

A major advantage of the MAVT framework is that it has a solid and testable axiomatic foundation. In addition, the numerical representation is relatively simple so that MAVT models are quite transparent, which makes it easier to understand how the decision recommendations depend on the estimated parameters.

The Analytic Hierarchy Process

In the Analytic Hierarchy Process (AHP) (Dyer and Forman, 1992; Saaty, 1977, 1980), the decision problem is structured as a hierarchy where the topmost element represents the overall decision objective. This element is decomposed into sub-objectives which are placed on the next highest level and which are decomposed further into their respective sub-objectives until the resulting hierarchy provides a sufficiently comprehensive representation of the relevant objectives. The decision alternatives are presented at the lowest level of the hierarchy.

The elicitation of preferences is based on the use of a ratio scale. Specifically, for every objective on the higher levels of the hierarchy, the DM is requested to compare the relative importance of its sub-objectives through a series of pairwise comparisons. In each such comparison, the DM is asked to state how much more important one sub-objective is than another (e.g., "Which is the more important objective, criterion, cost or quality?") and to indicate the answer on a 1–9 verbal ratio scale (1 = equally important, 3 = somewhat more important, 5 = strongly more important, 7 = very strongly more important, 9 = extremely more important). For the lowest level objectives, the DM is asked to carry out similar comparisons about which decision alternatives contribute most to the attainment of these objectives.

In the AHP, the derivation of the priorities is based on the following eigenvector computations. First, the ratio statements are placed into a pairwise comparisons matrix A such that the element A_{ij} denotes the strength of preference for the i th sub-objective over the j th one. From this matrix, a local priority vector w is derived as a normalized solution to the equation $Aw = \lambda_{w\max} w$ where $\lambda_{w\max}$ is the largest eigenvalue of the matrix A. Second, using these local priorities, aggregate weights for the objectives are derived by first assigning a unit weight to the topmost objective. This weight then "flows" downward in the hierarchy so that the weight of an objective is obtained by multiplying the weight of the objective immediately above it with he local priority vector component that corresponds to the lower level objective (taking the sum of such products if the lower level objective is placed under several higher level objectives). The weight of an alternative is obtained by summing all these products over those objectives that have not been decomposed into subobjectives.

In group settings, the AHP can be employed in many ways. For instance, stakeholder groups can be represented by "objectives" that are placed immediately below the topmost element of the hierarchy, whereafter pairwise comparisons can be elicited in order to associate corresponding importance weights with the stakeholders. Alternatively, the group members can provide their individual pairwise comparisons in a shared hierarchy where aggregation techniques are employed to synthesize their comparisons. They may also work in close collaboration, with the aim of arriving at consensual judgements for each pairwise comparison (see Basak and Saaty, 1993; Forman and Kirti, 1998).

Despite its popularity, the AHP has been subjected to major criticisms. In particular, the AHP may exhibit so-called rank reversals (Belton and Gear, 1983) whereby the introduction of an additional alternative may change recommendations concerning the *other* alternatives. This possibility – which is caused by the normalization of local priority vectors – violates the rationality axioms of MAVT and it is one of the reasons why some scholars have contested the merits of the AHP as a sound decision support methodology (Dyer, 1990). Other caveats in the AHP include the insensitivity of the 1–9 ratio scale and the large number of pairwise comparisons that may be needed when the number of decision alternatives is large (Salo and Hämäläinen, 2001). Yet, it can be shown that the pairwise comparisons are reformulated so that they pertain to value differences, then the results of the AHP analysis can be expected to coincide with those of MAVT (Salo and Hämäläinen, 2001).

Methodological Extensions

The above descriptions summarize the "basic" features of commonly employed MCDA methods. These methods and yet other methods have been extended in numerous ways:

- *Recognition of partial or inconclusive evidence*. Most MCDA methods assume that complete information about the model parameters can be elicited in terms of exact point estimates. Yet, such estimates can be excessively difficult or prohibitively expensive to acquire. This recognition has spurred the development of methods which represent incomplete information through *set inclusion* or, more specifically, through *sets* of parameters that contain the "true" parameters (see, e.g., Dias and Clímaco, 2005; Kim and Ahn, 1997; Kim and Choi, 2001; Salo and Hämäläinen, 1992, 2001). This modeling approach can be particularly useful in group decision making, because the sets can be defined so that they contain the parameters that correspond to the group members' individual preferences (Hämäläinen and Pöyhönen, 1996; Hämäläinen et al., 1992; Salo, 1995). Even if the resulting decision model may not provide conclusive recommendations for choosing the group's preferred alternative, it may still help determine which alternatives do *not* merit further attention so that the later phases of the analysis can be focused on other alternatives. A further advantage of set inclusion is its relative simplicity in comparison with methods that are based on evidential reasoning (Yang and Yu, 2002) or fuzzy sets (Herrera-Viedma et al., 2007).
- *Aggregation of individual preference statements*. In group decision support, the aggregation of individual preference statements into a group representation can be supported through various approaches, for instance (i) by assigning weights to the group members so that their weights reflect the perceived "importance" of the group members (Keeney and Raiffa, 1976), (ii) by computing averages from the group members' individual estimates (Basak and Saaty, 1993), or (iii) by forming wide enough interval statements that capture the preferences of all group members (Hämäläinen et al., 1992). In some cases, the members need not even approach the problem using the same problem representation: in the Web-HIPRE software

(Hämäläinen, 2003; Mustajoki and Hämäläinen, 2000), for instance, the group members may examine the problem using their own individual value trees, whereafter recommendations for group decision are generated by attaching importance weights to the group members.

- *Interfacing MCDA models with other decision support tools*. In many decision contexts, information about the impacts of the alternatives is generated with other modeling tools. In such cases, MCDA models can be usefully interfaced with or even integrated into other tools, because this may expedite the evaluation of decision alternatives, contribute to enhanced communication, and facilitate the implementation of decision recommendations. For example, the Web-HIPRE tool has been incorporated into the RODOS decision support system for the prediction of radiation exposures associated with nuclear emergency scenarios so that the system provides timely guidance for the prioritization of countermeasures for mitigating the impacts of an emergency (Geldermann et al., 2009; Hämäläinen, 2003).

Group and Decision Characteristics

The development of MCDA-assisted decision support processes needs to be based on a well-founded appraisal of the decision context. This involves a broad range questions about what is really at stake in the decision, who the stakeholders are (Friedman and Miles, 2006), and which group members will be engaged in the decision support process:

- *Decision makers and their needs*: Who are the decision makers? What is their role in relation to the decision problem? Which stakeholders are affected by the decision? What expectations are placed on the group decision support process? Is it sufficient to provide just a decision recommendation, or is there a need to justify and legitimize the recommendation? Is it the right time to launch a decision support process, in the sense that there is a sense of urgency among the decision makers, but no far-reaching commitments have yet been made to any of the alternatives? In general, the process should be initiated early enough, because this will leave more time for the possible generation and analysis of additional alternatives, which in turn is likely to contribute to enhanced decision quality.
- *Group members and group process*: Have the group members collaborated on earlier occasions? Is it likely that strongly opposing viewpoints will be presented? What is the prior level of trust that exists among the group members? Is there a willingness to collaborate in a consensus-seeking spirit in an open dialogue (Slotte and Hämäläinen, 2005)? How can the facilitator best promote trust among the group members?
- *Level of knowledge*: How familiar are the group members with the decision problem? What aspects of the decision problem do the group members have knowledge on? How will the relevant sources of knowledge be captured during the process?
- *Possibilities for the use of support tools*: How much time and effort can the group members devote to the process? What methodological tools are best aligned with such requirements (e.g., workshops, video conferences, internet-based surveys)? What temporal, technical, and budgetary constraints apply to the decision making process?

Furthermore, the characteristics of the decision problem can be clarified through questions such as:

- *Time for decision making*: By what time is the decision to be made? Are there possibilities for either hastening or postponing decision making? Is it possible to organize iterative decision support processes where results from the early phases inform later one?
- *Reversibility and flexibility*: Can the decision be modified or revoked later on? If so, What implications do these possible flexibilities have for the definition of the consequences of the different decision alternatives?
- *Presence of uncertainties*: How much is known about the different decision alternatives and their consequences? Can the major uncertainties be reduced? If so, when, how, and at what cost? Is the decision support process likely to benefit from initial scenario studies which provide early learning experiences and offer guidance for the collection of data?
- *Reoccurrence of decisions*: Has a related or similar problem been addressed before? If so, is it

possible to re-use earlier decision models in support of current decision making needs?

The above questions help determine how much time and effort should be invested into the development of an MCDA-assisted decision support process (see also Phillips, 1984). For instance, the case for making an major investment is most compelling in decision problems where the impacts are significant, the decision is inflexible and irreversible, and where there is ample time for the analysis. Also, if it is expected that the same decision problem will be encountered repeatedly, a sizeable investment may be warranted even if it would not be justified by the significance of a single isolated decision. In the presence of high uncertainties, it is pertinent to ask if it would be advantageous to postpone the decision, in the expectation that some uncertainties will be resolved so that more information could be used to generate a decision recommendation later on. Indeed, the key initial decision is whether or not the decision should be taken now or later.

Another key consideration is whether the decision is to be taken in isolation or possibly in connection with other decisions. Specifically, if the group members are addressing several decisions together, it may be possible to apply methods of portfolio decision analysis to develop recommendations that may be superior to those reached by analyzing individual decisions one-by-one (see, e.g., Efremov, 2008). This is because these methods help identify portfolios of "win-win" recommendations which are deemed acceptable by most or all group members.

Design of MCDA-Assisted Decision Support Processes

The careful consideration of the decision problem, and its relations to decision makers and stakeholders, is a key initial step in the design of an MCDA-assisted decision support process. In effect, this design task involves choices about the controllable characteristics of the decision process. Due to the large variety of decision contexts and the large number of MCDA methods, however, it is not possible to provide straightforward guidelines for this design task. Similarly, it is not possible to make general conclusions about which methods are "best" across the full range of decision contexts, given that the relative advantages of different MCDA methods differ from one decision context to another.

These differences notwithstanding, the development and deployment of MCDA-assisted decision support processes often involve steps such as:

- *Identification of the potential need for MCDA approaches*: A starting point for the development of a MCDA-assisted group decision making process is the recognition of a decision problem which can benefit from an explicit articulation of multiple criteria and alternatives. This early stage – which is often quite 'nebulous' – may benefit from the deployment of various problem structuring methods and soft systems approaches (such as CATWOE Checkland, 1989) which may yield some insights into the possible benefits that may be achieved through more formal modeling efforts.
- *Elaboration of decision context*. This involves the explicit identification of the *decision* that is to be supported, in view of questions such as: Who are the decision makers? Which organizations and stakeholders groups are impacted by the decision and how? What commitments and timeframes are involved? Will the same decision problem be encountered repeatedly, or does the decision pertain to one-of-a-kind problem?
- *Identification of participants*. The identification of the group members who will be engaged part in the MCDA process either as decision makers, sources of expertise, or as representatives of stakeholder groups is an important phase that is largely guided by an early analysis of the decision context. To ensure the trustworthiness of the process, it is therefore helpful to address considerations such as comprehensiveness and balance. For instance, are all relevant interests and sources of information duly represented? Or are some stakeholders disproportionately under/overrepresented?
- *Design of the decision support process*. The detailed design of the process involves choices about what MCDA methods will be used and how these methods will be deployed. The process often benefits from an explicit specification of the *roles* in which the group members take part in the process. For example, some group makers may take part in the identification of the relevant decision criteria, in view of their understanding of the organization's

values and objectives; but they may also take part in the process as suppliers of factual information about the impacts of the different alternatives. Particularly in long-lasting policy processes, different groups may participate in different stages and in different tasks. For instance, there could be a small initial core group for the structuring of the MCDA model, followed by the prioritization activities of a larger group and the synthesis of results by a steering group. In general, the design phase should yield a clear plan of how the process will be carried out. Such a plan is likely to enhance the legitimacy of the process. It may also serve as communication tool which clarifies how the different groups members can expect to benefit from their participation (Hämäläinen et al., 1992).

- *Enactment of the decision support process*. This involves the use of the MCDA methodologies and tools in accordance with the process design, going through phases such as the elaboration of the values, objectives and criteria; elicitation of preferences; development of alternatives; assessment of decision alternatives; synthesis of decision recommendations; and discussion of results, possibly in a workshop setting where the relevant decision makers are present. While adherence to the process design is often useful, there may also be situations where it is pertinent to adjust it in response to feedback that accumulates in the course of the decision support process (see, e.g., Hämäläinen et al., 2001; Marttunen and Hämäläinen, 2008). Also, when using methodologies, attention must be given to the possibility of procedural biases and ways in which these can be best avoided (Pöyhönen et al., 2001).
- *Evaluation of the decision support process*. The *ex post* evaluation of the decision support process – in view of dimensions such as relevance of decision recommendations or the uptake and implementation of decision recommendations – can offer reflective insights and valuable learning experiences which are needed when building cumulative competencies in decision modeling (see, e.g., Hämäläinen et al., 2009; Montibeller et al., 2008).

The choice of an external facilitator is another important design issue. Decision makers are rarely experts in MCDA methodologies, and consequently a neutral facilitator can be essential in ensuring that these methodologies are deployed constructively and productively. The specific competencies and past expertise of the facilitator should be explicitly recognized during the design phase. In particular, the MCDA process should not be designed "in the abstract", resulting in mere role descriptions, without considering the specific competencies of the individuals who will enact these roles.

MCDA Methods in Action

We next exemplify the use of MCDA methods in group decision support in view of selected case studies. Our selection is necessarily limited and merely highlights the key aspects of MCDA support, particularly in the light of more recent applications that reflect advances in methods and tools. For earlier and more extensive reviews, we refer to Bose et al., 1997; Vetschera, 1990; Matsatsinis and Samaras, 2001; and Wallenius et al., 2008).

Mustajoki et al., (2007) (see also Hämäläinen, 1988; Hämäläinen et al., 2000; Mustajoki et al., 2006) consider the development of models for the assessment of alternative strategies in response to a nuclear emergency situation. These models – which were constructed through a close dialogue with key decision makers (see also Hämäläinen et al., 2000) – made it possible to evaluate different remediation alternatives with regard to the attributes that captured main impacts (e.g., human health, social impacts, economic losses, environmental impacts). An important benefit of using these models repeatedly in facilitated workshops was that the learning experiences allowed the decision makers to acquire a better understanding of relevant alternatives and tradeoffs. Many of these models and decision support tools (such as Web-HIPRE) have been subsequently incorporated into RODOS, a real-time on-line decision support system which supports the development of countermeasure strategies in recognition of different time horizons (Geldermann et al., 2009). It is of interest to note that the use of MCDA tools for nuclear power issues in Finland began already in the 1980s when the Parliament of Finland discussed whether or not a fifth nuclear reactor should be constructed. At that time, MCDA tools served to clarify differences of opinion among different political groups (Hämäläinen, 1988).

Könnölä et al., (2010) report a case study where national research priorities for the forestry and forest-related industries were developed in three months by engaging more than 150 people. Due to the tight schedule, the process relied extensively on the web-based solicitation of prospective research themes proposed by members of the research community. The themes were then commented on and evaluated by specifically appointed reviewers with regard to three criteria: feasibility, novelty, and industrial relevance. Based on these valuations, shortlists of most promising themes were generated with the Robust Portfolio Modeling (RPM) methodology (Leisiö et al., 2007). The final priorities were developed in decision workshops where the RPM results helped ensure that the attention could be focused on the themes that appeared most promising in view of the preceding consultation and multi-criteria evaluation process. Analogous RPM-based processes have supported the development of strategic product portfolios (Lindstedt et al., 2008) and the establishment of priorities for international research and technology development programmes (Brummer et al., 2008, 2010).

Hobbs and Meier, (1994) describe a comparative study where several MCDA methods where employed for planning of a resource portfolio for Seattle City Light. In this study, planners and interest group representatives applied different preference elicitation techniques – such as direct weight assessment, tradeoff weight assessment, additive value functions, and goal programming – which were then compared in terms of their perceived ease of use and several validity measures. The participants noted that the MCDA methods did promote insights and increased their confidence in decision making; yet no single method emerged as the best one. The results also suggested two or methods should be ideally applied in conjunction, because this would generate additional insights and allow for consistency checks against biases.

Barcus and Montibeller, (2008) describe a MCDA model that was used to support decisions concerning the allocation of team work in a major global software company, subject to the demands that arise from technical complexities, multiple communication lines and stakaholders' divergent interests. This model was built in close collaboration with software development project managers, based on MAVT and decision conferencing. It addressed both software engineering attributes as well as "soft" and strategic issues, such as team satisfaction and training opportunities. Its deployment contributed to improve organizational learning, most notably by uncovering earlier inconsistencies in the communication of strategic objectives and by improving the communication of project managers' concerns to other managers.

Bell et al., (2003) consider uses of MCDA methods in integrated assessment (IA) where the aim is to capture interactions of physical, biological, and human systems so as to better understand long-term consequences of environmental and energy policies (e.g., limits on greenhouse gas emissions, and other strategies for the mitigation of climate change). Specifically, they organized a workshop where climate change experts used several MCDA methods for the ranking of hypothetical policies for abating greenhouse gas emissions, using data outputs from integrated assessment models. These methods did help group members understand policy tradeoffs as well as complex interdependencies among value judgments, data outputs and recommended decisions. Inspired by encouraging results of their case study, (Bell et al., 2003) outline alternative approaches for the use of MCDA methods in integrated assessment.

Merrick et al., (2005) conducted a multiple-objective decision analyis in order to assess the quality of an endangered Virginian watershed and to guide efforts towards improving its future quality. In their case study, the group members represented a broad range of expertise and perspectives, such as stream ecology, environmental policy, water hydrology, sociology, psychology, and decision and risk analysis, among others. The group members' values and goals were brought together using a watershed management framework that explicated the multiple criteria in maximizing the quality of the watershed. Specifically, the resulting MCDA framework helped identify significant value gaps and contributed to the shaping of programs for improving the quality of the watershed.

Bana e Costa et al., (2006) helped the Portuguese Institute for Social Welfare to adopt a systematic and transparent decision process for the development and renewal of the social infrastructures whose role is to provide funding and services to children, the elderly and the disabled. This process – which was based on decision conferencing and multicriteria modeling – engaged key decision makers in the three main phases of problem structuring, evaluation and prioritization. The proposed socio-technical process was seen to improve the transparency of decision making, the "rationality" of resource allocation decision, and the cost-effectiveness of decisions.

Belton et al., (1997) report experiences from the development of strategic action plans for the Department of a large UK Hospital Trust. Their case study was based on the combined use of (i) the strategic options and strategic analysis (SODA) in the problem structuring phase and (ii) the MAVT-analysis during the evaluation of decision alternatives. The study was carried in a 2-day facilitated workshop where the joint use of different methodologies helped the group make progress towards the definition of a shared strategic direction while it also promoted a shared and improved understanding of key issues. Building on this case study, Belton et al. also discuss what benefits may arise from the integration of these two approaches, and what implications such an integration has for the development of methodologies and tools.

Hiltunen et al., (2009) report experiences from a case study where Mesta, an Internet-based decision-support tool, was employed for the development of forest management strategies for state-owned forests (see also the chapter by Hujala and Kurttila, this volume). Based on an explicit recognition of the stakeholders' objectives and the examination of strategy alternatives with regard to five evaluation criteria, the strategy alternatives were categorized based on the threshold levels 'acceptable' or 'not acceptable' with respect to each criterion. The user interface of Mesta allowed these thresholds to be holistically adjusted until acceptable solutions that also satisfied production possibilities were found. Once the stakeholders had set their own thresholds in Mesta, they then negotiated until they were able to agree on the forest management principles that were then implemented in two regions.

In many countries, MCDA tools are widely applied in problems of water and environmental management (Hajkowicz, 2008), (Kangas et al., 2008; Kiker et al., 2005). For example, the Finnish Environment Institute has adopted systematic processes in order to guide its decisions on water regulation (Marttunen and Hämäläinen, 2008). In many ways, these processes also illustrate the different phases we have discussed in this chapter, particularly as concerns the identification and involvement of stakeholders; collaborative and iterative development of alternatives; MCDA-assisted evaluation of alternatives in workshops; and communication of results to citizens over the Internet. These processes are noteworthy in that they have paid explicit attention to potential biases and their mitigation.

Rationales for the Deployment of MCDA Methods

The above case studies, among many others, illustrate the benefits of MCDA methods in group decision making. Indeed, there are complementary *rationales* for the deployment of MCDA methods (Table 1):

- One of the key rationales for using MCDA methods is enhanced *transparency*. This is achieved when the group members' understand the structure of the MCDA model and the interdependencies between the model outputs (alternatives' MAVT values, decision recommendations) and the model inputs (scores, attribute weights) (see Bana e Costa et al., 2006; Geldermann et al., 2009; Hodgkin et al., 2005; Mustajoki et al., 2007). Such an understanding will create trust in the decision recommendations and also promote commitment to the decision implementation. Transparency also offers support for learning processes where the group members

Table 1 Rationales for the deployment of MCDA methods

Rationale	Brief definition	Benefits in group decision support
Transparency	Relationships between model inputs and decision recommendations can be readily understood	Supports learning by showing how changes in model inputs are related to the recommendations
Legitimacy	Process appropriately embedded in its institutional and organizational context	Lends authority and credibility Facilitates the implementation of decision recommendations
Audit trail	Availability of a track record of the consecutive steps enacted during the support process	Permits reflective *ex post* evaluations of the process Enhances learning
Learning	Enhanced understanding among group members about each others' perspectives and the decision problem	Helps recognize alternatives that are accepted by group members Process found rewarding by group members

can be explore interactively how changes in the input parameters will be reflected in the decision recommendations (Gelderman et al., 2009; Salo, 1995).

- The *legitimacy* of the decision support process is often a key concern, particularly in problems such as environmental planning where the decisions impact several stakeholder groups (Hajkowicz, 2008; Kiker et al., 2005). Indeed, even if a less formal decision support processes might lead to the same decision outcome, a model-based approach may still be warranted because it ensures, among other things, that alternatives will be treated consistently within a comprehensive evaluation framework.
- The use of MCDA methods typically leaves an *audit trail* that records the steps through which the decision recommendation was arrived at. The availability of such an audit trail can be particularly valuable in situations where the decision may have to be reached under considerable time pressure (e.g., emergency management, Bertsch and Geldermann, 2008; Gelderman et al., 2009), but where there is a need to improve the quality of these processes, which suggests that they should be subjected to scrutiny later on. At best, audit trails may suggest instructive "lessons learned" that serve to improve the quality of decision making processes (see also the chapter by Ackermann and Eden, this volume).
- The collaborative development and deployment of a shared MCDA model foster *learning processes* which, at best, help group members understand both the factual dimensions of the decision problem and each others' perspectives. This learning can be quite important: for instance, it may facilitate the shaping of alternatives that are likely to be accepted by all group members. Moreover, learning can be an inherently rewarding experience which generates interest in model-based approaches even in further decision problems as well.

There are even further benefits that can be sought after. For instance, the development of an MCDA model for a specific decision context may result in generic modeling frameworks that can be deployed in other contexts as well. Such a reuse and adaptation of decision models may offer *cost savings*, because the development of the MCDA model need not be started from the beginnings. It may also contribute to the attainment of *quality objectives*. Yet, some caution is called for when introducing existing models into other contexts, because the contexts need to be sufficiently similar (e.g., characteristics of decision objectives, evaluation criteria, group members, decision alternatives). The reuse of decision models may not necessitate any essential changes in the model structure: however, the learning aspects of the process may warrant particular attention, because model reuse may not require equally thorough processes of initial deliberation.

Outlook for the Future

The outlook for MCDA methods looks promising due to the potential of structured problem solving methods in addressing complex decisions. This potential is further amplified by recent technological and methodological developments:

1. *Technological progress in ICT*: The rapid diffusion of advanced information and communication technologies (ICT) offer enhanced possibilities of interfacing group members with MCDA models. For instance, mobile devices can be employed to solicit preference statements from the participants via text messages, and these devices can be used for the dissemination of results as well (see, e.g., Hämäläinen, 2003). It has also become easier to incorporate different kinds of inputs in decision models so that both quantitative data (e.g., scores, weights, values) and qualitative data (e.g., verbal descriptions, visual images) can be handled in an integrated manner. This kind of an integration will enable the development of decision support tools that contain "richer" information in contexts such as *e*-democracy (French et al., 2007; see also the chapters by Kersten and Lai and Schoop, this volume); yet the availability of tools does not suffice without learning from good practices (Hämäläinen et al., 2009). Furthermore, it is plausible that repositories of model templates will become popular within some communities of group members for specific decision problems. Such templates may contain useful information about the problems that are being addressed, and they may ensure that good modeling practices are applied consistently in

problems that are encountered repeatedly (see, e.g., Hämäläinen, 2004).

2. *Adoption of multi-modeling approaches*: Many MCDA methods are good at synthesizing and visualizing group members' preferences by using numerical representations. Yet the standard methods offer relatively static representations that do not necessarily capture dynamical cause-and-effect relationships, or verbal arguments that underpin stated preferences. In consequence, it may be useful to complement MCDA methods with other approaches that serve to enrich the decision support process. Examples of these approaches include, among others, causal maps (Montibeller and Belton, 2006), reasoning maps (Montibeller et al., 2008), cognitive maps (Eden, 2008), reference point approaches (Lahdelma and Salminen, 2001; Lahdelma et al., 2005), system dynamics (Brans et al., 1998; Santos et al., 2002; see also the chapter by Richardson and Andersen, this volume), agent reasoning (see also the chapter by Sycara and Dai, this volume), and argumentation analysis (Matsatsinis and Tzoannopoulos, 2008).
3. *Joint consideration of multiple decisions through portfolio modeling*: In many problems, decision makers have to address multiple decision items in conjunction. This is because the group members' preferences on one decision item may depend on what decisions are taken on the other issues (cf. composing a meal). The decision items may also be linked through shared constraints: this is the case, for example, when allocating resources to different organizational units, because the resources that are given to any one unit will have an impact on how much resources remain available for the others (see Kleinmuntz, 2007). These kinds of interdependencies can be captured through methods of portfolio decision analysis (see, e.g., Liesiö et al., 2007, 2008; Phillips and Bana e Costa, 2007) which offers recommendations on all decision items jointly. Even if there are no interdependencies among the items, portfolio modeling can still be helpful, because it allows the group members to search for decision combinations that would be acceptable to all group members. However, some caution is needed when increasing the number of items that are covered simultaneously, because the development of single large model that is applicable to all items may be difficult to develop and apply.
4. *Evaluation of the impacts of MCDA methods*. The development and deployment of MCDA methods can benefit significantly from the systematic evaluation of the impacts of these methods on the decision support process. Here, statistical analyses of controlled and well-designed experiments may, in principle, provide information about the comparative merits of different approaches, even if such experiments can rarely be conducted in real decision making situations. Controlled experiments can also provide information about in what decision contexts and in what ways different biases are likely to influence the recommendation (see, e.g., Davey and Olson, 1998; Pöyhönen et al., 2001). But because controlled experiments cannot replicate the full richness of real decisions, there is a strong need for reflective analyses of high-impact MCDA case studies. Such analyses should not focus narrowly on the MCDA methods and their properties. Rather, they should encompass the broader contextual problem characteristic and report "lessons learned" and "good practices" that help design and implement decision support processes in other contexts well.

The above observations suggest possibilities of extending MCDA-assisted processes by harnessing latest technologies, multiple methodologies, or explicit interfaces to other systems. Yet, the development of these extensions needs to build on an appraisal of whether the benefits of more encompassing models outweigh the additional efforts that are required. Even if the ultimate aim is to develop integrated planning environments that embody multiple methodologies and offer automated links to other modeling environments, it may best to proceed incrementally and to add additional components iteratively, because such an iterative approach offers useful learning experiences on the way.

There are growing pressures to improve the quality of decision making processes, particularly when decisions are taken recurrently and when they have contentious and far-reaching impacts. Here, quality has many dimensions, such as the ability (i) to adequately represent the group members' preferences, (ii) to derive and communicate well-founded decision recommendations, and (iii) to ensure the legitimacy, consistency, transparency and comprehensiveness of these processes. Of these closely intertwined quality dimensions, the first pertains mostly to methodology, while the second calls for support tools and the third one requires that the decision support process is properly embedded in its organizational context. As a potentially promising development, the quest for higher quality may create demand for dedicated decision models which have been adapted to specific decision problems and which can be effectively re-deployed by re-using existing data sets and by building on earlier experiences. One may even envisage that such models will be reviewed externally to ensure the adequacy of decision models in view of their intended uses.

Conclusion

We conclude this chapter by reasserting our belief in the major potential of MCDA methods in complex group decision making contexts. As demonstrated by numerous applications, MCDA methods offer structured frameworks for addressing multi-faceted problems where group members' preferences can be captured and synthesized into well-founded decision recommendations. By doing so, these methods foster collective learning processes and generate a better shared understanding of how the decision alternatives relate to the decision objectives.

MCDA methods can also be pivotal in improving the *quality* of decision processes so that demands for transparency, coherence, consistency, and comprehensiveness can be met. The attainment of such quality objectives is facilitated by recent methodological advances, improved availability of tool support and, quite importantly, by the growing body of reflective reports on case studies which demonstrate how MCDA methods can be successfully employed in different problem contexts. We also contend that MCDA methods merit to be studied also by those who have a a broader interest in group decision and negotiation, for because these methods are quite central in group decision support and because current methodological and technological developments open up exciting opportunities for the further advancement of the field.

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