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Multicriteria Methods for Group Decision Processes: An Overview

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Abstract

Important decisions are often taken by groups of decision-makers who need to choose among several alternatives in view of multiple objectives, in recognition of the interests of stakeholders. Such decision problems can be supported with the methods and processes of multicriteria decision analysis (MCDA) which foster collaboration, lend structure to the decision process, and help in managing problem complexity. In this chapter, we examine rationales for using MCDA methods in group decision processes, outline typical phases of these processes, summarize widely used MCDA methods and discuss some of their recent methodological extensions. We also provide guidelines for the design and implementation of MCDA-assisted group decision processes, based on an examination of behavioral factors and a structured review of selected case studies. We conclude with an outlook for the future in light of recent developments and trends.

Introduction

Important decisions with multiple objectives and alternatives often involve group decision-making (see, e.g., Keeney and Kirkwood 1975, French 1986, Belton and Stewart 2002, French et al. 2009, Greco et al. 2016). The problem is to find a course of action that contributes to the attainment of objectives that are seen as important by the members of the decision-making group. Even if the decision is taken by a single individual, the decision typically affects several stakeholders whose interests need to be recognized. Thus, it may be helpful to design and implement structured decision support processes in which these stakeholders' views are systematically charted.

The literature on multicriteria decision analysis (MCDA) offers numerous methods for addressing problems characterized by multiple objectives (for textbooks and surveys, see, e.g., Belton and Stewart 2002, Wallenius et al. 2008, French et al. 2009, Parnell et al. 2013, Greco et al. 2016). The articulation of the objectives can be useful for many reasons: for instance, it fosters the identification, elaboration, and prioritization of alternatives (Keeney 1992). For example, the elaboration of safety-related objectives, such as *reducing the number of accidents*, *reducing the severity of injuries in accidents*, or *providing faster access to first-aid services*, can stimulate the generation of alternative measures for improving safety. The systematic concretization of such objectives in terms of corresponding evaluation criteria and attendant measurement scales provides a framework for assessing how the alternatives contribute to the attainment of these objectives. Within this framework, information about the decision-makers' subjective preferences can be modeled through the elicitation of criteria weights and the evaluation of alternatives with regard to the relevant criteria. Finally, overall evaluations of the alternatives (or a ranking of the alternatives) can be produced by combining criterion weights with the criterion-specific evaluations. Thus, the MCDA methods help synthesize both values and facts, in order to generate well-founded guidance for decision-making.

Typically, a notable benefit of deploying MCDA in group decision process is that of fostering increased understanding of the decision problem in its broader context. Thanks to its systematic structure, the MCDA process can help group members consider the problem from multiple perspectives, explore the possible consequences of the decision, and recognize how others perceive the problem, for instance. Moreover, the group can benefit from the process as a result of enhanced communication and the articulation shared as well as conflicting views. These benefits are among the key reasons for the wide adoption of MCDA methods in supporting group decision-making in application areas like environmental management (Gregory et al. 2012).

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, subject to the assumption that his or her preferences comply with stated rationality axioms (Keeney and Raiffa 1976; von Winterfeldt and Edwards 1986). Extensions of these theories into group settings underpin development of MCDA methods which admit and aggregate information about the group members' preferences, which gives insights into which alternatives are preferred to others by the individual group members as well as by the group as a whole (see, e.g.,Keeney and Kirkwood 1975, Keeney 2013).

In MCDA processes, the group members can be, for example, *decision-makers*, representatives of *stakeholders* who are impacted by the decision, or *experts* providing information or methodological modeling support to the decision process. Often, there is also a process *facilitator* (see, e.g., Phillips and Phillips 1993, Franco and Montibeller 2010). A group decision process creates a temporary organization and assigning a *leader* is often useful (Hämäläinen et al. 2020). Commonly, this role is assumed by or explicitly granted to the facilitator. The number of group 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 et al. 2010).

In this updated version of the chapter by Salo and Hämäläinen (2010) in the previous version of the *Handbook of Group Decision and Negotiation*, we restrict our attention to multicriteria decision analysis. For example, we do not discuss the many variants of voting procedures considered in Nurmi (2020) and Kilgour (2020). Nor do we cover game theoretic approaches discussed by Kibris (2020); conflict analysis methods covered by Hipel et al. (2020); multicriteria agency models (Vetschera 2000); or bargaining models where the group members (or agents) pursue different objectives (see, e.g., Ehtamo and Hämäläinen 2001, Mármol et al. 2007).

Rationales for Using MCDA Methods

From the perspective of enhancing and ensuring the quality of decision processes, there are several rationales which motivate the use of MCDA methods. As shown in Table 1, these include support for the management of complexity, increased transparency and legitimacy, the formation of an audit trail, and enhanced collaborative learning:

Rationale	Brief definition	Benefits in group decision support
Management of complexity	MCDA offers tools for managing the complexity involved in major decision problems	Helps to systematically consider decision problem from multiple perspectives and to combine subjective evaluations with multiple sources of data
Transparency	The results are based on explicitly stated values, facts, and assumptions in an understandable way	Reduces the risk that the results are driven by biases, false assumptions, or hidden motives. Supports learning
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 which enhances learning
Learning	Enhanced understanding among group members about each other's perspectives and the decision problem	Helps find areas of agreement and disagreement. Process found rewarding by group members

Table 1 Rationales for the deployment of MCDA methods

- MCDA provides support for *the management of complexity* in many-faceted and far-reaching decision problems where the number of issues to be accounted for can be truly large. Specifically, MCDA methods lend structure to complex decision problems, which is useful for guiding discussions as well as modeling and data collection efforts, for example. They also help formulate well-founded conclusions based on the consideration of diverse perspectives and complementary sources of data. The rationale of managing complexity is particularly salient in problems of portfolio decision analysis (Salo et al. 2011), because without adequate methodological support, it may be impossible to examine all portfolios which, by definition, consist of combinations of individual alternatives.

- Enhanced *transparency* is another key rationale. This is achieved when the group members understand the structure of the MCDA model and the interdependencies between the model outputs (e.g., the overall evaluations or the ranking of the alternatives) and the model inputs consisting of beliefs about facts (e.g., criterion-specific evaluations of alternatives) and subjective value judgments (weights of the criteria) (see Bana e Costa et al. 2006; Geldermann et al. 2009; Hodgkin et al. 2005; Mustajoki et al. 2007). Such an understanding fosters trust in the results and promotes commitment to the implementation of decision recommendations. Transparency also supports learning processes where the group members can explore interactively how changes in the input parameters will be reflected in the results (Geldermann 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 affect several stakeholder groups (Hajkowicz 2008; Kiker et al. 2005). Indeed, even if a less formal decision support process might lead to the same decision outcome, a model-based approach may still be warranted because it ensures, among other things, that the alternatives will be treated consistently, systematically, and on equal terms 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, Geldermann et al. 2009, Papamichail and French 2013), but where there is a need to improve the quality of these processes, which suggests that they should be subjected to scrutiny later on. Audit trails may suggest instructive “lessons learned” that serve to improve the quality of decision-making processes. The audit trail may also help reflect on how the results of the process could have been affected by behavioral phenomena such as cognitive biases and help design processes that mitigate the risk of biases (see also Lahtinen et al. 2017a; Zare et al. 2020).

- 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, such as the likely magnitudes of the possible consequences of the decision, and each other's 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. It is also possible that the decision-makers' preferences change as they learn more about the problem. In effect, learning can be an inherently rewarding experience which generates interest in model-based approaches even in further decision problems as well.

Phases of MCDA-Assisted Group Processes

While MCDA methods differ in their underpinning theoretical and methodological assumptions, the processes through which they are deployed often share many similarities (e.g., Belton and Stewart 2002; French et al. 2009; Wallenius et al. 2008). At a high level of aggregation, these processes commonly consist of the following partly overlapping and iterative phases:

1. *Clarification of the decision context and the identification of group members*: In this phase, the aim is to clarify the overall situation in which the MCDA process takes place, including aspects such as what the broader aims of the process are, what the decision is really about, who the member of the decision-making group and the other stakeholders are, and in what role the participants will be engaged in the process (e.g., as decision-makers, sources of expertise, or representatives of their respective stakeholder groups (cf. Belton and Pictet 1997)). In high-level decisions which are to be taken by senior decision and policy makers, MCDA processes can be enacted with the aim of providing information to the actual decision-makers without involving them extensively in the process. Yet, even in this situation, it can be advantageous to involve at least someone from the high- level decision-making group in the MCDA process in order to ensure that the high-level concerns are reflected in framing the problem, distilling insights, and communicating the results.

2. *Identification and explication of decision objectives*: In this phase, the objectives related to the decision are identified and explicated. The objectives can relate to the full range of tangible and intangible concerns, including the aims and goals of the decision-makers and relevant stakeholders. Many kinds of techniques (e.g., in-depth interviews, workshops, questionnaires) can be used to ensure that all relevant objectives are identified. In the identification of objectives, it can be fruitful to start from the *values* that are important to the members of the decisionmaking group and stakeholders and to proceed by formulating objectives based on these (Keeney 1992, 1996). Next, the objectives need to be elaborated by developing corresponding evaluation criteria and associated measurement scales with the help of which the attainment of the objectives can

be assessed (see, e.g., Keeney and Gregory 2005). Ideally, the set of criteria should be comprehensive (i. e., all relevant objectives are addressed) and nonredundant (i.e., no double counting of benefits or harms related to alternatives).

3. *Generation of decision alternatives*: In this phase, the aim is to specify a representative yet manageable set of alternatives. Even if some alternatives may have been identified before the MCDA process, deliberate attempts at generating further alternatives should be made, because the process may be compromised by "errors of omission" if promising alternatives are not included in the analysis. Keeney (1992) and Siebert and Keeney (2015) describe how the objectives identified in the previous phase can be used to stimulate the generation of alternatives. Other techniques can be found, e.g., in Sternberg (1999) and Colorni and Tsoukiàs (2020). All alternatives need to be specified sufficiently well so that they can be evaluated with respect to the criteria.

4. *Elicitation of preferences*: In this phase, subjective preference statements are solicited, for example, about criterion-specific weights which indicate how important the different evaluation criteria are relative to each other and how much value the group members associate with the alternatives' performance levels on criterion-specific measurement scales. Thus, the responses by different group members typically differ due to differences in their preferences. The use of debiasing techniques is recommended (see, e.g., Montibeller and Von Winterfeldt 2015, Lahtinen et al. 2020).

5. *Evaluation of decision alternatives*: All alternatives are measured with regard to every decision criterion using an associated measurement scale. These measurements can be based, among other things, on empirical data, quantitative models, or subjective judgments. The subjective judgments may be solicited from external experts or from the group members themselves.

6. *Analysis and communication of results*: The results are typically represented as the overall values of the alternatives (sometimes called overall scores), computed from the elicited parameters of the decision model in keeping with the calculation schemes of the chosen MCDA method. Another format for presenting results is a ranking of alternatives which does not convey information about preference differences between the alternatives. Usually sensitivity analyses are carried out to examine how the results would be affected by changes in the values of numerical parameters. Interactive workshops are often held, e.g., to enhance learning, increase transparency, and support communication. It may be pertinent to revisit the earlier phases of the process and to re-specify alternatives or objectives, if this is deemed warranted due to changes in the group members' perception of the problem.

The possibility of revising earlier phases is often warranted, because the group members' understanding of the problem evolves over time. For example, the examination of tentative results may lead to the recognition of additional objectives or stimulate the generation of further alternatives. There may be changes in the decision-makers' preferences as well, as these preferences are partly constructed during the decision support process (see, e.g., Slovic 1995, Payne et al. 1999). Especially in entirely new decision contexts, an iterative process may be useful in that it helps generate tentative initial results for learning purposes before proceeding to the later rounds.

In MCDA-assisted group processes, the facilitator often has an essential role in ensuring that the group members' views are properly charted and that each group member has a chance of voicing his or her concerns. This is important especially in face-to-face workshops. The facilitator also has a critical role in ensuring that (i) methodologies are employed correctly, taking into account the pitfalls of human decision biases, (ii) the group members are aware of the underlying methodological and modeling assumptions, and (iii) the results of the decision model are understood. Franco and Montibeller (2010) provide an extensive discussion of the facilitator's role and relevant facilitator skills.

In some cases, the group members need not approach the problem using the same problem representation (see, e.g., Keeney 2013). In the Web-HIPRE software (Hämäläinen 2003; Mustajoki and Hämäläinen 2000), for example, the group members can first examine the problem using their own individual value trees, whereafter recommendations for the group decision can be generated by associating importance weights to the group members.

Because the evaluation of alternatives with regard to the criteria builds on multiple information sources, it may be possible to carry out this activity in a decentralized mode so that the participants evaluate alternatives only with regard to those criteria they are knowledgeable about. Furthermore, the elicitation of preference information can be supported with Internet-based decision support tools (Hämäläinen et al. 2010). Such tools may be indispensable in extensive MCDA processes characterized by the need to engage a very large number of participants who represent different stakeholder groups.

We next summarize the main features of two widely used MCDA methodologies, noting that there are numerous other MCDA approaches as well. Matsatsinis and Samaras (2001) discuss so-called preference disaggregation methods in group MCDM. See also Camillere and Zarate (2020), Ren et al. (2020), Corrente et al. (2020), and Wachowicz and Roszkowska (2020) in this handbook.

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 (Keeney and Raiffa 1976; French 1986; Belton and Stewart 2002). 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 multiattribute 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). 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 multiattribute value function, defined on the alternatives' consequences, such that alternative x is preferred to y if and only if

$$x \succcurlyeq y \Leftrightarrow V(x) = \sum_i v_i(x_i) \geq \sum_i v_i(y_i) = V(y). \qquad (1)$$

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

$$V(x) = \sum w_i v_i(x_i), \qquad (2)$$

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., $\sum w_i = 1$.

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

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

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 decision problem can be adequately modeled using MAVT and to elicit score and weight parameters carefully, with the aim of mitigating the possibility of biases.

The Analytic Hierarchy Process

In the analytic hierarchy process (AHP) (Dyer and Forman 1992; Saaty 1977, 1980, 2005), 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-to-9 verbal ratio scale (1 equally important, 3 somewhat more important, 5 strongly more impor- tant, 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 $Aw \; \lambda_{wmax} w$ where λ_{wmax} 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 the 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 sub-objectives.

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 judgments for each pairwise comparison (see Basak and Saaty 1993; Forman and Peniwati 1998). Group decision-making with the AHP is discussed also by Moreno-Jimenez (2020).

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-to-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 1997). 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 1997).

Methodological Extensions

The above descriptions summarize the “basic” features of two commonly employed MCDA methods. These and many other methods have been extended in a number of ways:

- *Incorporation of partial or incomplete information*. Most MCDA methods assume that information about the model parameters can be characterized through exact point estimates. Yet, the recognition that such estimates can be difficult or expensive to acquire has spurred the development of methods in which incomplete information is represented either with intervals or *sets* of parameter values that contain the “true” values (see, e.g., Kim and Ahn 1997, Kim and Choi 2001, Salo and Hämäläinen 1992, 2001, Punkka and Salo 2013). See also de Almeida et al (2020a). One advantage of the set inclusion representation is its simplicity in comparison with approaches such as evidential reasoning (Yang and Xu 2002) and fuzzy sets (Herrera-Viedma et al. 2007), for instance. In group decision- making, the intervals can be defined so that they contain the parameter values that correspond to the group members' individual preferences (Hämäläinen et al. 1992; Salo 1995; Hämäläinen and Pöyhönen 1996; Vilkkumaa et al. 2014). While the resulting decision model may not provide conclusive recommendations for the group's preferred alternative, it may help determine which alternatives do *not* merit further attention, allowing the later phases of the analysis to be focused on the other alternatives.

- *MCDA and multi-modeling*. In many decision contexts, information about the impacts of the alternatives is generated with modeling tools such as prediction or simulation tools. In such cases, MCDA models can be usefully interfaced with or even integrated into the other tools. For example, the MCDA model can be used for the overall evaluation of strategies whose performance with respect to multiple criteria has been assessed with a system dynamics model (see, e.g., Brans et al. 1998, Santos et al. 2002). Environmental decision-making is one context in which the use of multiple modeling tools in combination is common (Voinov et al. 2016). For example, the Web-HIPRE MCDA 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 (Hämäläinen 2003; Geldermann et al. 2009). Furthermore, MCDA can be integrated with different problem structuring and stakeholder methods which are often important in group settings (Marttunen et al. 2017). Methods that could be used together with MCDA include also causal maps (Montibeller and Belton 2006), reasoning maps (Montibeller et al. 2008), cognitive maps (Eden 2004), reference point approaches (Lahdelma and Salminen 2001; Lahdelma et al. 2005), and argumentation analysis (Matsatsinis and Tzoannopoulos 2008).

- *Spatial decision-making*. MCDA methods are increasingly used to help address spatial decision problems (Malczewski 2006; Greene et al. 2011; Malczewski and Jankowski 2020). Such problems typically call for the evaluation of alternative locations for industrial or other facilities or the evaluation of alternatives which have geographically varying outcomes. In this context, the multicriteria data is visualized as map layers in geographical information systems (GISs). The use of GISs brings in additional aspects such as how information can be best presented with maps and what impacts the GIS software has on the MCDA process (Ferretti and Montibeller 2016; Malczewski and Jankowski 2020). Spatial decision-making has given rise to new theoretical results, too (see, e.g., Harju et al. 2019). In siting problems such as the siting of facilities, one affected stakeholder group consists of the potential neighbors of the facility: thus, there may be a need to involve a large number of citizens in the decision support process (see, e.g., the wind farm siting study in which a GIS-based decision support system was developed for the collaboration between the planners and the public over the web (Simao et al. 2009)). The adequate involvement of the public can be a key enabler of perceived success, because the public can provide information and views from the local level, whereas the planners and the experts are viewing the decision problem from the strategic level. In the earlier GIS-based MCDA literature, attention has been given to the aggregation of preferences (Malczewski and Rinner 2015). Recently, there has been growing interest in considering group aspects more broadly (Jelokhani-Niaraki 2019, 2021; Malczewski and Jankowski 2020).

- *Portfolio decision analysis*. In many problems, decision-makers have to address multiple decision items in conjunction (Salo et al. 2011). Such problems arise, for example, in environmental management, where the decision-makers may seek to identify a good set of policy actions to cut greenhouse gas emissions or to purchase many pieces of land to form a conservation network (see, e.g., Lahtinen et al. 2017b). The decision items are usually 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 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 "win-win" decision combina- tions that would be acceptable to all group members. Yet caution may beneeded when increasing the diversity of items that are assessed simultaneously, because it may be difficult to develop a single model which would be meaningful and applicable to very different kinds of items.

Behavioral Issues and Biases

The behavioral perspective is important in the practice of MCDA because people from diverse backgrounds are involved in a process in which preferences and other subjective issues are central. Behavioral factors such as biases and socio-emotional dynamics influence the effectiveness of the MCDA process. *Biases* are behavior- and judgment-related tendencies. For example, the loss aversion bias refers to a tendency to assign more importance to changes that are perceived as losses instead of gains. The so-called motivational biases relate to strategic or unintentional advancement of own interest or the interests of a stakeholder. A recent review of biases in MCDA is provided by Montibeller and Von Winterfeldt (2015). For an extensive list of cognitive biases in general, see Wikipedia (2020). Behavioral issues are almost always present in model-based interventions (Hämäläinen et al. 2013; Franco and Hämäläinen 2016).

Behavioral factors should be considered both in the design of the MCDA group process and in its actual implementation. First, it is important to become aware of behavioral factors and their possible influence. Reflecting on one's own behavior and the behavior of the group may suggest ways to improve the process or to correct poor choices made earlier. Second, there are bias mitigation techniques and other practices which can help to reduce the risks of biases and other behavioral effects. The following ideas and questions are examples of things that can be considered:

- *Behavioral impacts and process design*: Behavioral phenomena interact with procedural choices such as the framing of preference elicitation questions. For example, due to the loss aversion bias, it can matter whether the hypothetical questions used in preference elicitation are framed as losses or gains. Also the choice of measuring stick attributes to be used in the preference elicitation phase can impact the results (see, e.g., Anderson and Hobbs 2002, Lahtinen and Hämäläinen 2016). Due to the measuring stick bias, the alternatives that are strong in the measuring stick attribute may become favored in the process. Another example is the splitting bias, whereby an objective could receive too much weight if it has been split to too many sub-objectives (Pöyhönen et al. 2001; Hämäläinen and Alaja 2008). Procedural choices can also stimulate or hinder socio-emotional phenomena such as trust generation. The problem-solving team may consider questions such as the following: What are the behavioral factors such as cognitive or motivational biases that can influence the decision process? What are the possible impacts of these factors in each phase of the process? Do the biases and other behavioral factors pose risks and could these risks be mitigated? For example, should the risk of narrow thinking be mitigated, e.g., by increasing group heterogeneity or by appointing a "Devil's advocate" whose role is to challenge the assumptions made by the group and to bring up alternative perspectives in discussions? How is the process documented and evaluated from the behavioral perspective?

- *Mitigation of biases*: Biases pose a risk particularly if their effects are likely to accumulate, thereby favoring some given alternative or a subset of alternatives so that the rank order of the alternatives is affected. General approaches for mitigating biases include, e.g., the use of iterative processes with consistency checks and feedback, the use of multiple approaches, and the averaging of results obtained with different approaches. Furthermore, a number of bias mitigation techniques are presented in Montibeller and Von Winterfeldt (2015), and these may be helpful. Lahtinen et al. (2020) describe new techniques for mitigating risks related to loss aversion and the measuring stick effect and also for preventing the accumulation of biases. The design of bias mitigation can also be assisted by computational analyses. This may help to tailor the bias mitigation techniques for the situation at hand and also to help prioritize bias mitigation efforts.

- *Socio-emotional phenomena*: Human decision-making is an emotional process, and group behavior is strongly driven by socio-emotional dynamics (Faure et al. 1990; Leppänen et al. 2018; Martinovsky 2015). See also Martinovski (2020) and Filzmoser (2020). This needs to be taken into account in how group members are engaged. One example of socio-emotional dynamics is the group think phenomenon (Janis 1982) in situations where the group makes consensual choices without critical consideration of alternative viewpoints. The risk is greater in highly cohesive groups. It is necessary to consider how socio-emotional effects are to be accounted for during the process and in its facilitation. A dialogical approach can be useful (see Slotte and Hämäläinen 2015). Even the location of workshops and their physical setup merit attention.

- *Trust and interaction*: 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? Should the facilitator promote trust among the group members and how? Furthermore, to ensure the trustworthiness of the process, it can be 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- or overrepresented?

- *Path dependency*: The facilitators (and even other members) of group decision processes need to recognize that usually there are alternative paths that can be taken in the decision support process and that these paths can lead to different outcomes. Path is the sequence of steps taken in the MCDA process – it represents the actual realization of the planned process. It is created from the interactions between all the factors in the problem-solving process including the people involved and their assumptions, expertise, and interests, and also the methods used, and the contextual aspects. Major forks along the path include, for example, the choice of the group members, how the decision problem is defined, the choice of the MCDA method and the preference elicitation techniques used, and how the decision alternatives are evaluated with respect to the criteria. Considering the path offers an integrative perspective which can help understand the overall impact of behavioral phenomena (see Hämäläinen and Lahtinen 2016; Lahtinen and Hämäläinen 2016).

Guidelines for Designing MCDA-Assisted Decision Support Processes

Against the backdrop of the processual, methodological, and behavioral considerations outlined in the previous sections, we next provide guiding questions and suggestions to support the design of MCDA processes. However, we also note that due to the huge variety of decision contexts and many variants of MCDA methods, it does not appear warranted to provide definitive guidelines. Yet, design steps such as the following can be considered:

- *Identification of the potential need for MCDA approaches*. A starting point for the development of an MCDA-assisted group decision support process is the identification of a decision problem which can benefit from an explicit articulation of multiple criteria and alternatives. Already in this step, the initiators of the MCDA process have a tentative understanding of the decision problem and the context, the real decision-makers and the stakeholders, etc. The case for making a major commitment to and investment in a formalized decision support process is most compelling in problems where the decision consequences are significant, the decision is irreversible, and there are reasons for not postponing the decision substantially and when there is ample time for the analysis. Also, if it is expected that the same decision problem will be encountered on a recurring basis, a sizeable investment may be warranted even if it would not be justified by the significance of a single isolated decision. Depending on the problem context, the MCDA process can be limited to the initial phases without proceeding to data collection or quantitative modeling, as these initial activities may be sufficient for increased understanding and improved communication, for instance. Moreover, it may be pertinent to assess what benefits the adoption a multi-modeling approach could bring.

- *Setting up the project*. At the outset of the design, the issue of project leadership (Hämäläinen et al. 2020) needs to be considered. Assigning the leadership role to a designated individual with sufficient knowledge and authority can help the group keep the big picture in mind while ensuring that the process is impartial and that fair documentation is produced. The leader can be, e.g., the modeling expert, facilitator, or representative of the body commissioning the study. In general, the personal and professional competence profile of the facilitator is an important design issue. Representatives of the stakeholders are rarely experts in MCDA methodologies, and consequently a facilitator with strong methodological skills can be essential in ensuring that models are deployed correctly and productively. The specific competencies and past expertise of the facilitator should be explicitly recognized during the design phase (see, e.g., Franco and Montibeller 2010, Ormerod 2014). 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. In this phase, it can be relevant to consider also what constraints (e.g., temporal, technical, and budgetary) apply to the decision support process.

- *Elaboration of decision context*. This phase essentially consists of systems thinking regarding the decision problem and the interconnected systems related to the problem. This involves the explicit specification of the *decision* that is to be supported, assisted by guiding questions such as the following: Who are the real and final decision-makers? What is their role in relation to the decision problem? Do the decision-makers expect that the process produces a decision recommendation, or do they seek to receive information more generally, e.g., about stakeholder views or the alternatives? Which organizations and stakeholder groups are impacted by the decision and how? What commitments and time frames are involved? Is there a need to justify and legitimize the results? Can the decision be modified or revoked later on? Will the same decision problem be encountered repeatedly, or does the decision pertain to one-of-a-kind problem? Another key consideration is whether the decision is to be taken in isolation or in connection with other decisions.

- *Identification of participants*. The identification of the group members who will be engaged in the MCDA process either as decision-makers, as sources of expertise, or as representatives of stakeholder groups is an important step which is largely guided by the preceding steps of problem identification and elaboration. In order to build legitimacy and trust, it is pertinent to address considerations such as comprehensiveness and diversity of participants. For instance, are all relevant interests and sources of information represented? Or are some stakeholders disproportionately under /overrepresented? Furthermore, how familiar are the group members with the decision problem? On what aspects of the decision problem do the group members have knowledge?

- *Design of the decision support process*. The detailed design of the process involves a series of choices about which MCDA methods will be used and how they will be deployed. These design choices need to be viewed from several perspectives, including the behavioral one and the viewpoint of practicality. The temporal order of the process steps also calls for close attention, because it may have significant consequences due to behavioral effects (Hämäläinen and Lahtinen 2016). See also Eden (2020). Checkpoints can be planned into the process, where the group can review the results from the completed steps and possibly redirect the process (Lahtinen et al. 2017a). Overall, the process design can benefit from an explicit specification of the different *roles* in which the group members participate in the process. Here, it can be fruitful to consider the cognitive styles of the group members; see Damart and Adam-Ledunois (2020). Some group members 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, for example. 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 addition, the design should acknowledge how much time and effort the group members can devote to the process and which methodological tools are best aligned with such requirements (e.g., workshops, video conferences, Internet-based surveys). Another question is which, if any, software tools should be used (see, e.g., Mustajoki and Marttunen 2017). If the group members address several decision problems together, it may be possible to apply methods of portfolio decision analysis to develop solutions that may be superior to those reached by analyzing individual problems one by one (Salo et al. 2011). The portfolio approach can help at identifying portfolios of "win-win" recommendations which are deemed acceptable by most or all group members. There is an extensive literature on the design of participation in general which could also be considered. Bayley and French (2008) provide a discussion from the perspective of group decision- making literature. 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 group members can expect to benefit from their participation (Hämäläinen et al. 1992).

- *Execution of the decision support process*. This involves the use of the MCDA methodologies and tools in accordance with the process design, proceeding 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. In some situations it may be pertinent to adjust the design 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). The execution of the process may benefit from the involvement of a "Devil's advocate" whose role is to challenge the assumptions made by the group and to bring up alternative perspectives in discussions.

- *Evaluation of the decision support process*. In the ex post evaluation of the decision support, it is necessary to consider, e.g., to what extent the context may have changed and were the right stakeholders included in the process. Moreover, the ex post assessment frameworks proposed by Schilling et al. (2007) and Hamilton et al. (2019) consider criteria such as transparency, creativity, dialogue orientation, efficiency, satisfaction, and impact, to name a few. Reflecting on the possible impacts of biases and other behavioral effects is also important (see, e.g., Hämäläinen et al. 2010, Scott et al. 2016, Zare et al. 2020).

MCDA Methods in Action

In this section, we exemplify the use of MCDA methods in the light of selected case studies demonstrating some key aspects of MCDA-based group decision support.

Mustajoki et al. (2007) (see also Hämäläinen 1988; Hämäläinen et al. 2000; Mustajoki et al. 2006) consider the development of models for assessing 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 online decision support system which supports the development of countermeasure strategies in recognition of different time horizons (Geldermann et al. 2009). The use of MCDA tools for nuclear power in Finland started 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. (2011) report a case study where national research priorities for the forestry and forest-related industries were developed in 3 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 designated 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 (Liesiö 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 most promising themes in view of the preceding consultation and multicriteria evaluation process. Analogous RPM-based processes have supported the development of strategic product portfolios (Lindstedt et al. 2008), the establishment of priorities for international research and technology development programs (Brummer et al. 2008, 2011), and the selection of infrastructure maintenance projects at the Finnish Transport Agency (Mild et al. 2015). An interesting feature of the application presented in Mild et al. (2015) is that the RPM methodology was applied repeatedly over several consecutive years.

Harris-Lovett et al. (2019) describe a collaborative decision analysis process in which MCDA methods were combined with stakeholder analysis and scenario planning to support nutrient management in the San Francisco Bay Area. In this application, the aim was to engage people in thinking about the issues, to improve communication, and to collect information. More specifically, there was an interest to find areas of agreement and disagreement among stakeholders, to evaluate alternative options from a range of perspectives, and to identify issues requiring further investigation. Initially, interviews were carried out with 32 stakeholders in order to better understand the decision-making context, to develop objectives and scenarios, and also to collect ideas concerning possible nutrient management alternatives, for example. Subsequently, nine stakeholders were involved in the preference elicitation phase and in the evaluation of decision alternatives. These nine stakeholders were selected using a cluster analysis technique so that the selected stakeholders' views would represent the opinions of the larger set of stakeholders as comprehensively as possible. The quantitative results of this study included the overall evaluations of alternatives under three future scenarios. The preference statements by different stakeholders were not aggregated. Rather, insights were sought by comparing the results based on the statements expressed by different stakeholders. Interestingly the authors suggest that the low ranking of one of the alternatives could be explained with the lack of familiarity concerning the technology that the alternative is based on. This demonstrates how the results of the MCDA process may depend on the people involved.

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 in which climate change experts used several MCDA methods to rank hypothetical policies for abating greenhouse gas emissions, using data outputs from integrated assessment models. These methods helped 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.

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 perceived 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 toward 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. (1997) 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.

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; Linkov and Moberg 2011). 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 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 explicit attention has been paid to potential biases and their mitigation. Most recently, there has been an interest in discovering and mitigating biases related to the structuring of the objectives hierarchy, i.e., the value tree (Marttunen et al. 2018, 2019).

Outlook for the Future

The outlook for MCDA methods appears promising due to the increasing importance of understanding, managing, and acting in complex wholes with multiple stakeholder groups and multiple interests. This endeavor calls for structured problem-solving approaches. Furthermore, in order to succeed, these approaches and accompanying tools must be applied with due care. In particular, it is crucial to pay attention to the behavioral and socio-emotional phenomena arising in the group situation as well as to the correct use of tools:

1. *The behavioral perspective brings in new ideas and methods*. Recently, the behavioral perspective has gained increasing attention as expressed by the introduction of the term behavioral operational research (BOR) (Hämäläinen et al. 2013; Franco and Hämäläinen 2016). Within this lively stream of research, researchers have introduced new perspectives and methods that help develop the practice of group MCDA. One example is ethnomethodology which has helped understand the phenomena occurring in real-time live situations; see Franco and Greiffenhagen (2020). Also the role of emotions is receiving increasing interest (Martinovski 2020). These trends are likely to affect how MCDA is carried out in practice. For example, it may become possible to use emotional stimuli beneficially in creative processes or to utilize procedures designed to minimize the fear of losing face. Furthermore, advances in neuroscience help understand cognitive and emotional phenomena related to group decision-making. For example, methods of neuroscience have been recently employed to study the inquiry and advocacy modes as well as related emotions in group decision-making (Leppänen et al. 2018). Roselli et al. (2019) used neuroscience methods to inform the development of data visualizations. See also de Almeida et al. (2020b). Recently, there has also been rapid development in the areas of big data and affective computing (see, e.g., Shoumy et al. 2020). This can mean that there will be direct ways to evaluate and even to generate emotional responses in computer-supported group settings, which can give rise to ethical issues as triggering emotions can influence decision-making. Emotional criteria can perhaps be more often seen in the MCDA models used in group decision-making in the future. The mitigation of biases is an important practical question, which is attracting increasing attention. One possibility is to use computational simulations to assist in the design of bias mitigation strategies before engaging the real group members (Lahtinen et al. 2020).

2. *Technological progress*. Recent advances with information and communication technologies offer new possibilities for interfacing group members with MCDA models. For instance, mobile applications can be utilized to invite preference statements or other judgments from the participants. Moreover, virtual meetings over the Internet are associated with a host of new challenges and opportunities. 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 material) can be synthesized. Such an integration will enable the development of decision support tools that contain richer information, for example, in the context of *e*-democracy (Hämäläinen 2003; French et al. 2007). MCDA methods can help in the development of large-scale group participation systems (Klein 2020), which are connected, e.g., to big data and social media. Digital platforms are becoming increasingly common in many areas, and it is likely that they will in the future include group collaboration platforms where MCDA methods could be available. The important questions to be addressed with the use of technological developments include, e.g., how remote collaboration over the web influences the formation of trust (Yearworth and White 2020). Gamification and serious games is an emerging technological field which offers a broad array of new methodologies that can prove useful in participatory processes. For a recent survey, see Bakhanova et al. (2020). One could use gamification, e.g., in the preliminary analysis and problem structuring phase without explicitly involving the real decision-makers. Gamification can also be used together with agent-based modeling to evaluate potential outcomes from different scenarios. It has already been tested in online preference elicitation (Aubert and Lienert 2019). Overall, technological progress will make the use of multi-modeling easier and more attractive.

3. *Building on experiences and creating competencies*. There is a strong need for reflective analyses of high-impact MCDA case studies. Such analyses should consider contextual problem characteristics as well as behavioral and socioemotional factors such as those highlighted by Martinovski (2020). The goal is to report lessons learned and good practices that help design and implement decision support processes in other contexts as well. For illustrative discussions in the area of environmental management, see, e.g., Hämäläinen (2015) and Lahtinen et al. (2017a). It is plausible that shared repositories of process and model templates will be created within communities of group members for specific decision problems (see, e.g., Cockerill et al. 2019). Such repositories could be embedded in online group collaboration platforms. More controlled and well-designed experiments are still needed, e.g., to design and evaluate ways of mitigating biases. At times, such experiments can be combined with real decision support processes (see, e.g., Hämäläinen and Alaja 2008). Furthermore, one needs to consider the development of professional competencies that are needed in facil- itation, as discussed, e.g., by Franco and Montibeller (2010) and Eden (2020). A further set of competencies is discussed by Hämäläinen et al. (2018) in relation to the concept of systems intelligence

(Saarinen and Hämäläinen 2004; Hämäläinen and Saarinen 2008) which refers to "our ability to behave intelligently in the context of complex systems involving interaction, dynamics and feedback." The systems intelligence-related competencies, i.e., systemic perception, attunement, positive attitude, spirited discovery, reflection, wise action, positive engagement, and effective responsiveness, serve to understand and improve the practice of MCDA. For example, attunement to the group problem-solving process can be important for effective collaboration.

Conclusion

We conclude this chapter by reasserting our belief in the pivotal contribution that MCDA methods can bring to the solution of complex group decision-making problems. As exemplified by the growing body of reported applications, MCDA methods offer structured frameworks for addressing multifaceted problems in which group members' preferences need to be captured and synthesized to inform decision- makers, often by way of producing well-founded decision recommendations. Many of the benefits of these methods stem from their ability to foster collective learning processes and to promote a shared understanding of the problem, including the many-faceted relations between decision objectives and decision alternatives.

MCDA-assisted group decision processes are more likely to succeed when there is a sound understanding of behavioral aspects, such as socio-emotional dynamics as well as cognitive and motivational biases. These aspects need to be accounted for in the design of the MCDA-based group process and its implementation. Even the process needs to be documented to support critical reflection and learning.

Overall, we believe that the potential demand for MCDA methods and tools in group decision support will continue to grow. One reason for this is that most of the significant problems faced by organizations are increasingly systemic in that they involve many interrelated issues and affect many stakeholder groups whose interests need to be acknowledged and accounted for. In addition, the development of new methodologies and technologies, combined with new perspectives into human behavior, opens up exciting opportunities for enhancing group decision processes with MCDA approaches.

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