Evaluation and Decision Models with Multiple Criteria

Case Studies

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Preface

The elaboration of this Handbook has a long and colorful history. The initial call for contributions goes back to Spring 2008. It was sent to colleagues we knew were engaged in applications of Multiple Criteria Decision Aiding (MCDA); the aim of the initial book project being to emphasize methodological issues and, in particular, appropriate application of existing procedures for modelling and aggregating preferences in view of aiding decision.

The book project emerged as an initiative of the *Decision Deck Project*[1] and was positively supported by COST Action IC0602 *Algorithmic Decision Theory*[2]. An early contact with Springer offered the opportunity to publish a Handbook on MCDA Applications in their "International Series". From the simple editing of a collection of individual papers, as planned in the beginning and aligning a list of MCDA applications, we shifted hence to an ambitious comprehensive Springer Handbook editing project, including furthermore a methodological part.

This move revealed more demanding and time consuming than anticipated. We succeeded in convincing the authors of the Evaluation and Decision Models book series (D. Bouyssou, T. Marchant, P. Perny, M. Pirlot, A. Tsoukiàs, and P. Vincke) to provide the required methodological part. It became also later opportune to add a chapter about XMCDA, a data standard to encode MCDA data in XML, and one about *diviz*, a software workbench to support the analyst in the decision aid process, both developed in the context of the Decision Deck Project.

Finally, we are in the position to present this Handbook to the reader. We would like to address here our apologies to our contributors for the resulting very long editing time, a time span which can explain why some references cited by the earliest contributors in this Handbook might not be the most recent. We acknowledge and take full responsibility for this inconvenience. However, we are convinced that

[1] http://www.decision-deck.org

[2] http://cost-ic0602.org/

this project became much richer. The book showcases a large variety of MCDA applications, within a coherent framework provided by the methodological chapters and the comments accompanying each case study. The chapters describing XMCDA and *diviz* invite the reader to experiment with MCDA methods, and perhaps develop new variants, using data from these case studies or other cases the reader might face. Every time the lessons and tools presented in this book contribute to the use of MCDA in classrooms or in real-world problems, we will feel our objective has been accomplished.

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The editors are thankful to all the chapter contributors for sharing some of their experience in applying MCDA, as well as the authors of the methodological chapters. We would also like to express our gratitude to the many reviewers invited to read and comment on initial drafts of the chapters, thus contributing to improve their organization and clarity.

This project would not have been possible without the support of the Decision Deck Consortium, the COST ACTION IC0602 “Algorithmic Decision Theory” and the GDRI Algodec. Also, Springer, by providing us the ambitious opportunity to edit a Handbook, contributed much to the actual content the reader will discover hereafter.

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Chapter 1
Introduction

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Abstract This introductory chapter explains, first, the strategy guiding the editing of the MCDA application case studies. The second section illustrates the overall organization of the handbook into three parts: - a concise methodological introduction to the concepts of decision aiding, preference modelling and recommendation building; - the main part with fifteen case studies of MCDA applications; - and a short third part devoted to support tools for the MCDA process. The chapter ends with listing some highlights of the book content.

1.1 The editing strategy

Our main goal with this book was to illustrate the rich diversity of aspects which is typical of multiple criteria decision problems. Decision aiding is a *process*. As such, it involves a series of actors (decision maker(s), stakeholders, experts, analysts, etc.); interaction and feedback play a crucial role. The activity of modelling the problem and the decision maker's preferences is more important and time consuming than the more technical part consisting in choosing and applying a method for aggregating the decision maker's (DM's) preferences. Formulating a recommendation to the DM is also a delicate part of the process.

In line with our desire to illustrate the complexity of the decision aiding process, we addressed the interested contributors the following guidelines for writing their application.

- The context of the case should be described: what is the decision problem, the decision maker(s), the stakeholders, the analysts, the alternatives, the criteria, the performances of the alternatives, ...?
- What have been the difficulties in the process of identifying or constructing these elements?
- Which method(s) has (have) been used ? How have the parameters of these methods been set?

- How did the decision aiding process evolve (main steps, feedback loops, branching, abandoned branches, ...)?
- Recommendation, decision.
- Comments on the case and on the decision aiding process.

The proposed framework underlies a way of conceiving a decision aiding process that is quite general. A wide range of applications fit in the model that is described in a formal way in the methodological part of this book (see Chap. 2). The study of decision aiding processes is a research domain in itself, in which there is still much work to be done. In particular, a detailed and operational description of this sort of process is required in view of building computerized decision aiding systems that could help analysts to monitor such processes.

The fifteen applications presented in Part II of this book describe examples of decision aiding processes. In view of emphasizing their salient features, we decided to add an individual editors' commentary to each application chapter. A common line of critical reviewing guidelines was therefore developed. The eventually chosen template for structuring our comments identifies five major aspects: application context, problem structuring, performance evaluation modelling, decision aiding process, tangibility and practical impact of results.

1. Context of the decision aid application
   - How does this application fit into the "big picture" of the book, and MCDA in general?
   - What was the objective of the decision aid intervention?
   - (Possibly:) Other objectives: e.g., had authors the objective of trying a novel method?
   - Who was the decision aid addressee?
   - What actors participated directly or indirectly?
   - Who acted as analyst and what was his role?
   - What phases can be identified and what was the time span of the decision aid process?
2. Problem structuring
   - (Possibly:) Use of problem structuring methods.
   - Type of result sought (problem statement[1]).
   - How was the set of alternatives defined ? Global characteristics of this set.
   - How was the set of evaluation criteria defined? Global characteristics of this set.
   - (Possibly:) Modelling of uncertainties.
3. Performance evaluation
   - MCDA model choice for aggregating criteria.
   - Elicitation process.
   - (Possibly:) How divergence among actors was addressed (aggregation, discussion, ...)
4. Process-related aspects

[1] In some of the contributed chapters of this book, the authors use the french word *problématique* when they refer to the problem statement.

- Client-analyst interaction.
- Reiterations.
- Interactions between phases.
- Sensitivity/robustness analysis.

5. Results
   - Tangible results: artifacts
   - Intangible results: knowledge, relationship among actors
   - Impact relatively to the objective of the decision process
6. Other remarks
   - Methodology aspects (questionable aspects, success factors, what else might have been tried).
   - Relevance of this application.

We hope that the case studies of MCDA applications may thus contribute to validate the general framework and permit to deepen the analysis of decision aiding processes, as a step towards the implementation of decision aiding monitoring systems.

1.2 Organization of the handbook

The Handbook is divided into three, unequal parts. A first methodological part, consisting of three chapters, gives insight into respectively the concepts and issues of a decision aid approach, the problem of constructing an aggregated perspective with multiple preference dimensions, and the building of convincing decision aid recommendations. The second and by far the main part consists of fifteen chapters devoted to present and discuss selected MCDA applications that will be introduced in detail hereafter in Section 1.2.2. Each application is followed by a short commentary. The last part, which describes tools to support the MCDA process, first presents the XMCDA data standard, before detailing the *diviz* software platform to design and execute MCDA methods.

1.2.1 Theoretical background

Besides aiming to contribute to the analysis of decision aiding processes, this book also aims at shedding some light on multicriteria decision methods, i.e. methods that aggregate the decision maker's preferences on the different criteria in an overall preference. Such methods make the necessary trade-offs between conflicting objectives, and yield a model of the decision maker's overall preference. A bunch of methods have been proposed since the 1950s. Some of them are inserted in elaborated methodologies, and all of them use more or less complex mathematical procedures (for panoramas of such procedures, see e.g. Vincke [1992], Roy and Bouyssou

[1993], Pomerol and Barba-Romero [2000], Belton and Stewart [2002], Ishizaka and Nemery [2013]).

The choice of an aggregation method is an issue in MCDA. Several papers in the literature deal with the selection of the most appropriate MCDA method depending on the decision problem, the type of data available, etc. [see e.g. Ozernoy, 1987, 1992, Hobbs et al., 1992, Guitouni and Martel, 1998, Polatidis et al., 2006]. Why such a diversity of methods? Is there a best one? Some authors - and most proponents of such methods - support this idea. Also, in applications, many analysts systematically use a particular method or a family of variants of a method. Our *credo* is different. We believe that some methods are better suited for some contexts and other for some other contexts. For instance, certain methods can naturally deal with qualitative evaluations. The logic underlying the aggregation of the criteria values in some methods may be more easily understandable by some decision makers than by some others. Or these may be more inclined to answer certain types of questions than other types. The logical analysis of the aggregation methods allows to produce a precise view of the strengths and weaknesses of the various models. It is possible, for instance, to determine which kind of preferences can be represented by a given method (through an axiomatic analysis of the methods or the preferences). Alternatively, the properties of the methods can be established, which allows to compare them and select one in a more informed way. Hence, in our view, the analyst should master several methods and be able to choose the most appropriate one in a given context.

Chapter 3 in Part I, entitled *Modelling preferences*, browses a picture of the main logic at work in usual aggregation procedures. More precisely, it characterizes the families of preferences that can be represented by some general types of models. This chapter does not provide a description of all aggregation methods used throughout the book. Instead, it analyzes general frameworks, into which most particular methods do belong. These frameworks allow to better understand the logic of aggregation implemented in the methods. Analysts can benefit from such a knowledge for improving the way they question decision makers about their preferences. Or, even better, to design methods that maximize the information yielded by each answer to well-chosen questions (*active learning*). In the applications we can see how the general aggregation principles were used and it may also be interesting to question the choice made by the analyst in charge. We observe that in some applications, several aggregation methods were used for the same decision problem, leading to decision recommendations that are likely to be more convincing.

A third methodological issue is the subject of the last chapter (Chap. 4) in Part I. This chapter is entitled *Building recommendations*. It deals with the last part of the decision aiding process. It uses the model of the decision maker's preferences that was built during the aggregation phase to derive a recommendation addressed to the decision maker. Such a conclusion is by no means a decision, the latter pertaining to the exclusive responsibility of the decision maker. The recommendation gathers the conclusions that appear sufficiently well-established to be valid independently on the remaining uncertainties about the decision maker's preferences (*robust conclusions*). Less robust conclusions can be part of the recommendation but these

should be accompanied with appropriate comments. The main source of the difficulty in formulating recommendations is that the decision maker's preferences may not be always fully determined and they are not, in general, perfectly reflected in the aggregation model. Chapter 4 reviews the different problem statements contexts (choosing, sorting, ranking) and specifies, in each case, a certain number of ideas that can be used to derive reasonably well-established recommendations.

1.2.2 Case studies of MCDA applications

The applications collected in Part II of this book span multiple countries, multiple fields, and multiple types of problems. In geographical terms, most applications occurred in Europe, with Belgium, France, and Greece represented in more than one case. The exceptions are two applications in African countries, coauthored by African and European authors. In terms of type of problem statement, the book presents choice, ranking, and classification problems. Nine out of the fifteen applications intend to eventually select the best alternative, although many of them perform a ranking or a classification of the alternatives as a modelling option. One classification method, ELECTRE TRI, is the aggregation approach used more often in this set of applications, but other approaches such as additive value aggregation (Chaps. 14 and 17), AHP (Chap. 18), and PROMETHEE (Chap. 19), among others, are also represented in the book. Table 1.1 provides a summary of the applications chapters, indicating these and other characteristics of each application.

Application	Field of application	Country	Goal	Problem statement	Method	Client type	Decision Maker(s)	Decision Support System
Ch.5 Choosing the Best Poster in a Conference	Jury decisions	Greece	Analysis of a problem	Choice	Condorcet method and RUBIS	Scientific association	Jury members	An existing software
Ch.6 Composite Web Service Selection	Internet services	France	Framework	Choice (by sorting)	ELECTRE TRI	Consumer	An individual	A prototype was developed
Ch.7 Site selection for a kindergarten	Education	Spain	Analysis of a problem	Choice (by ranking)	SMAA-III	Corporation	Group of decision makers	An existing software
Ch.8 Choosing a cooling system for a power plant	Energy/ environment	Belgium	Proof of concept (ex-post)	Choice (by ranking)	Weighted sum and ELECTRE II	Competence centre	Group of experts	Not mentioned
Ch.9 Localization of wind farm projects	Energy/ environment	France	Proof of concept	Choice (by ranking)	ELECTRE III	Public administration	Group of stakeholders	A SDSS was developed
Ch.10 Assessment of Data Centers Environmental Sustainability	Energy/ environment	Portugal	Framework	Sorting	ELECTRE TRI	Corporation	Group of experts	An existing software
Ch.11 Cost valuation of a nuclear-fuel repository	Energy/ environment	Belgium	Analysis of a problem	Choice (determining a value)	fuzzy inference	Public administration	Group of experts	A DSS was developed
Ch.12 Assessing the response to land degradation risk	Energy/ environment/	Burkina Faso	Framework	Sorting	ELECTRE TRI	(Public administration)	An expert	A SDSS was developed
Ch.13 Post-accident nuclear risk evaluation	Energy/ environment	France	Analysis of a problem	Sorting	ELECTRE TRI	Public administration	Group of stakeholders	A SDSS was developed
Ch.14 Hazardous material transport	Energy/ environment, transportation	Italy	Proof of concept	Choice (by ranking)	Weighted sum	Public administration	Group of experts	SDSS (custom adapted)
Ch.15 Rural Road Maintenance	Transportation	Madagascar	Proof of concept	Sorting	ELECTRE TRI	Public administration	Group of stakeholders	A DSS was developed
Ch.16 Evaluation of comfort	Transportation	France	Proof of concept	Sorting	ELECTRE TRI	State-owned company	Group of experts	Not mentioned
Ch.17 Evaluating hydrogen storage systems for future vehicles	Transportation	European Union (sponsor)	Proof of concept	Choice (by ranking)	MACBETH	(several corporations)	Group of experts	An existing software
Ch.18 Personal Financial Planning	Finance	Germany (authors)	Framework	Choice	Optimization and AHP	(generic)	An individual	A DSS was developed
Ch.19 Bank Rating	Finance	Greece	Analysis of a problem	Rating/scoring	PROMETHEE	Corporation	Group of experts	A DSS was developed

Table 1.1 Applications in this book.

The first chapters have diversified application domains, but share a common goal: to select the most preferred alternative. The chosen modelling options are however diverse. The chapter "The EURO 2004 Best Poster Award: Choosing the Best Poster in a Scientific Conference", by R. Bisdorff, addresses a problem of a decision by a jury intending to select a winner in a posters competition. It describes how the process unfolded and further (re-)analyzes the problem using a different approach. Chakhar et al.'s chapter "Multicriteria Evaluation-Based Framework for Composite Web Service Selection" presents a framework to evaluate webservices that need to be assembled for a particular purpose. Although the ultimate goal is to select one composition of services, it proceeds to classify the possible compositions according to quality of service classes. Chapter "Site selection for a university kindergarten in Madrid", by T. Tervonen et al., addresses the choice of one location among several candidate sites for a kindergarten, but approaches the problem using a ranking method.

Chapters 8 to 14 address applications related with the energy/environment field, which is clearly in this book, as it is probably in practice, the most popular application area for MCDA. Problems concerning the environment typically gather multiple actors in the decision process and involve evaluating many criteria that are not easy to convert into a single performance measure. The work "Choosing a cooling system for a power plant in Belgium" by M. Pirlot et al. intended to demonstrate the usefulness of MCDA to an industrial client by examining *a posteriori* a decision it had faced concerning a technology choice. In their chapter "Participative and multicriteria localization of wind farm projects in Corsica island: decision aid process and result", Oberti and Paoli provide an account of a decision process open to the general public that addressed a siting problem. Chapter "Multi-Criteria Assessment of Data Centers Environmental Sustainability", by M. Covas et al., addresses the assessment of environmental impacts of the data centers that underlie most common Internet and telecommunications services available today, proposing a classification framework.

Chapters 11 to 14 address a particular concern in applications dealing with the environment/energy field: risk. Kunsch and Vander Straeten's chapter "The cost of a nuclear-fuel repository: A criterion valuation by means of fuzzy logic" focuses on costs, namely on the problem of estimating the costs of a project by aggregating the opinions of different experts, the main concern being the risk of budget overrun. In chapter "Assessing the response to land degradation risk: the case of the Loulouka catchment basin in Burkina Faso", S. Metchebon et al. make an assessment of risks of land degradation, using a classification method to assign geographical locations to risk classes. Mercat-Rommens et al. also use a method to classify risks, in the event of an accident, for different geographical locations in their chapter "Coupling GIS and Multi-criteria Modeling to support post-accident nuclear risk evaluation". Their work considers not only risks to the environment and human health, but also risks for economic activities. Finally, the chapter "A multicriteria spatial decision support system for hazardous material transport", by A. Luè and A. Colorni, considers the choice of routes for transportation of hazardous materials, taking into account the risk of accidents. Chapters 12 to 14 (and also Chap. 9) have in common

the development of Spatial Decision Support Systems (SDSS), based on extending the capabilities of Geographical Information Systems (GIS) to deal with MCDA problems.

A. Luè and A. Colorni's chapter, together with the next three chapters, address transportation-related issues. In Chapter "Rural Road Maintenance in Madagascar. The GENIS project", A. Tsoukiàs and H. Ralijaona provide an account of their involvement in a project to classify roads with regards to their maintenance needs. Öztürk et al.'s chapter "On the use of a multicriteria decision aiding tool for the evaluation of comfort" also addresses a classification problem, aiming at assigning potential future railways rolling stock to comfort classes. The chapter "An MCDA approach for evaluating hydrogen storage systems for future vehicles", by F. Montignac et al., concerns a technology choice problem for future vehicles, which was addressed as a ranking problem.

The two final applications in this book are related with the field of finance (Chap. 11 is also loosely related to this field). Chapter "An MCDA approach for Personal Financial Planning", by O. Braun and M. Spohn focuses on the perspective of an individual, offering a portfolio optimization framework for planning personal finances. Chapter "A Multicriteria Approach to Bank Rating", by M. Doumpos and C. Zopounidis, concerns the perspective of a central bank who must rate commercial banks. Although rating is usually considered as a sorting problem, in this case a ranking method was used to derive a global performance value for each bank being evaluated.

There are a few aspects shared by many of the applications in these chapters that deserve some reflection. Although the set of contributed chapters cannot be interpreted as an accurate representation of the panorama of all MCDA applications throughout the world, these shared aspects will match what happens in many situations. The main aspect (not depicted in Table 1.1 because it applies to most chapters with very few exceptions) is the importance attributed to problem structuring. By going through these cases the reader will be able to appreciate the effort required to define the set of alternatives to be evaluated and the set of evaluation criteria, besides other discussions concerning the actors involved and the problem statement to be adopted. In many cases, most of the value of the analysis concerns this stage: after the problem structuring stage the following steps can be sometimes relatively easy.

The type of client commissioning the application varies. In some cases it is a publicly or a privately owned company, but in most cases it was some type of public administration entity (a regional administration, an agency, or other). Indeed, this type of "client" is the one most likely to value the added transparency brought by conducting an explicit MCDA analysis. Another concern of public administration (also shared by private organizations) is the need to involve many parties in decision processes. Indeed, most of the applications deal with multi-actor situations, involving a group of decision makers, or a group of experts, or a group of stakeholders potentially affected by a decision, including the general public. As demonstrated in these chapters, MCDA can be an excellent instrument to gather the interested parties and to model their potentially different concerns, in a joint problem-solving

activity. Nevertheless, true decision makers did not intervene much in most of the applications. Perhaps due to the nature of the client - often a public administration - the expression of priorities and preferences is delegated to experts and/or to stakeholders, rather than the person or a group of persons who have the authority to decide.

Another peculiar aspect emerging from this set of applications is that in many cases they are described as a proof of concept, a pilot study, or a demonstration project (all labeled as proof of concept in Table 1.1). In these cases, as the authors explain, the MCDA intervention was conducted to prove its value to the client. MCDA was applied on a no-problem (as in the case of an ex-post evaluation) or a small-scale problem, so that it would be approved and legitimated to be applied on a larger scale. Fortunately, in most cases, this demonstration was deemed successful.

Under the heading "Goal" in Table 1.1, the reader will see that some case studies are labeled "Framework". By this expression, we mean that the decision models involved are designed for a generic decision problem in a specific domain of application. In general, the proposed approach is illustrated on real data and expert evaluations, but the decision aiding process may be incomplete (e.g. there may be no definite decision maker). In contrast, the label "Analysis of a problem" refers to an actual decision aiding process for a specific instance of a decision problem and with a well-identified decision maker.

In most applications, there were tangible outcomes besides the answer to the initial problem statement. It is generally accepted that a factor that contributes to the popularity of MCDA is the availability of software. Indeed, the use of some software is reported in most of the applications in this book. It is noteworthy however that in some cases the software itself was developed on purpose for the particular application, thus remaining as a tangible tool on the hands of the client for the reiterated use of the models and knowledge developed during the intervention. In some cases, as already mentioned, the development consisted in building a SDSS, using a GIS as a starting basis.

Finally, maybe the biggest testimony of success in many of these applications, is the fact that the chapter is coauthored not only by MCDA analysts but also by someone from the client organization. This is not only an indication of approval, but also a sign that MCDA know-how was passed onto the client organization, which might now be able to conduct further analyzes without MCDA expertise from outside.

1.2.3 MCDA process support tools

The third and final part of the book consists of two chapters. First, Chapter 20, which describes XMCDA, a proposal for an MCDA data standard, and second, Chapter 21, which presents the *diviz* environment for multi-criteria decision analysis. Why these chapters? It was stated in the outset that the project of this book grew up in the framework of the Decision Deck Consortium, a gathering of researchers which aims at making publicly available software tools that allow to deal with multi-criteria de-

cision problems. The collaborative development effort of the consortium gave birth to various initiatives, among which a quite impressive set of web-services, which allow to access to elementary MCDA resources (aggregation algorithms, data treatment and visualization components, ...) in a unified manner. These calculation elements all speak a common language, namely XMCDA. This XML-based encoding standard for MCDA data and concepts, which is presented thoroughly in Chapter 20, allows to make these web-services interoperable. Consequently very naturally, the need for a tool to combine these calculation elements in complex workflows appeared. Chapter 21 presents the *diviz* workbench, which facilitates the construction of such calculation sequences via a very intuitive graphical user interface. This chapter also illustrates, on a didactic example, how *diviz* can be used to support a decision aiding process. The idea is to suggest that the reader could play the role of the analyst in all the case studies for which the evaluation and preferential data are available. In view of allowing for this, we asked the authors to make the data used in their application available to the reader (whenever this was possible). The reader can consequently reproduce the analyzes performed in the cases, test other hypotheses, apply other methods they may wish to try, or follow other methodologies. This also means that the cases, together with the *diviz* software, can be used for teaching purposes, e.g. for training students to act as analysts. What is particular to decision aiding, indeed, is the fact that numerical data is not enough to describe a problem. The context and sufficient information on the goals and preferences of the decision maker must be specified before a meaningful sequence of treatments can be proposed in view of "solving the problem". In most of the cases described in this book, a teacher can find enough material to design an exercise for training students to play the analyst's role in a realistic simulated decision aiding process. As such, *diviz* provides an adequate environment to support the students in their analyzes of the case and their experimentation with several methods.

1.3 Highlights

To summarize, this book may be useful:

- for studying the decision aiding process: the book contains the description of 15 cases of decision aiding processes in various domains of application and with contrasted characteristics. These case studies are commented within a decision aiding process framework that is described in the three initial methodological chapters. This corpus of case studies provides a basis for deepening a scientific analysis of the decision aiding process.
- for experimenting with a variety of MCDA methods in the realistic decision aiding situations described in the case studies. The *diviz* software platform provides a common framework for such an experimentation.
- for training students for the role of analyst by involving them in simulated decision aiding processes inspired from a case study. Again, the *diviz* platform is a suitable tool for supporting this training.

- for providing decision analysts with examples of decision aiding processes in which they could find inspiration for their own practice.

We trust the reader will find in the descriptions of the applications and the adjoined commentaries motivation and lessons useful to apply MCDA in all types of organizations, possibly using the tools described in the third part of this book. We are sure new lessons will emerge. And, who knows, the reader may share such lessons in a future book like this one.