
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 XM-CDA 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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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 Algodéc. 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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Contents

1	Introduction	1
	Raymond Bisdorff, Luis C. Dias, Patrick Meyer, Vincent Mousseau and Marc Pirlot	
1.1	The editing strategy	1
1.2	Organization of the handbook	3
1.2.1	Theoretical background	3
1.2.2	Case studies of MCDA applications	5
1.2.3	MCDA process support tools	9
1.3	Highlights	10
	References	11
 Part I Theoretical Background		
2	Aiding to decide: Concepts and issues	17
	Denis Bouyssou, Thierry Marchant, Marc Pirlot, Alexis Tsoukiàs and Philippe Vincke	
2.1	Introduction	17
2.2	The Decision Aiding Process	19
2.2.1	The problem situation	20
2.2.2	The problem formulation	21
2.2.3	The evaluation model	22
2.2.4	The final recommendation	23
2.3	Some Practical Questions	24
2.3.1	What is the problem?	24
2.3.2	What is a problem statement?	25
2.3.3	Stakeholders, Criteria, Uncertainties.	27
2.3.4	How to choose a method?	29
2.4	Conclusions	30
	References	33

3	Modelling preferences	37
	Denis Bouyssou, Thierry Marchant, Marc Pirlot, Alexis Tsoukiàs and Philippe Vincke	
3.1	Introduction	38
3.2	The additive value function model	39
3.2.1	Conjoint Measurement	40
3.2.2	Uniqueness issues	41
3.2.3	Marginal preferences within the additive value model ...	42
3.2.4	Leaning on the additive value model for eliciting preferences	43
3.2.5	Independence and marginal preferences	47
3.2.6	The additive value model in the “rich” case	48
3.2.7	Insufficiency of additive conjoint measurement	55
3.3	Models based on marginal traces	57
3.3.1	Decomposable preferences	58
3.3.2	Insufficiency of marginal analysis: marginal traces	59
3.3.3	Generalising decomposable models using marginal traces	60
3.3.4	Models using marginal traces	63
3.3.5	Properties of marginal preferences	64
3.3.6	Eliciting the variants	65
3.4	Models based on marginal traces on differences	66
3.4.1	The additive difference model	66
3.4.2	Comparison of preference differences	67
3.4.3	A general family of models using traces on differences ..	68
3.4.4	Eliciting models using traces on differences	71
3.4.5	Examples of models that distinguish no more than three classes of differences	72
3.4.6	Examples of models using vetoes	77
3.4.7	Examples of preferences that distinguish a large variety of differences	80
3.5	Weakly differentiated preference differences	82
3.5.1	Concordance relations	82
	References	85
4	Building recommendations	89
	Denis Bouyssou, Thierry Marchant, Marc Pirlot, Alexis Tsoukiàs and Philippe Vincke	
4.1	Introduction	89
4.1.1	Choosing	90
4.1.2	Ranking	90
4.1.3	Sorting	91
4.1.4	Outline	91
4.2	Using a value function	92
4.2.1	Choosing	92
4.2.2	Ranking	93

- 4.2.3 Sorting 93
- 4.3 Using several value functions 95
 - 4.3.1 Choosing with a set of additive value functions 95
 - 4.3.2 Ranking with a set of additive value functions 95
 - 4.3.3 Sorting with a set of additive value functions 96
- 4.4 Other preference models 97
 - 4.4.1 Motivating examples 97
 - 4.4.2 Choice procedures 99
 - 4.4.3 Ranking procedures 103
 - 4.4.4 Sorting procedures 106
- 4.5 Conclusion 109
- References 111

Part II Case studies of MCDA applications

- 5 The EURO 2004 Best Poster Award: Choosing the Best Poster in a Scientific Conference** 119
 Raymond Bisdorff
 - 5.1 The historical case 120
 - 5.1.1 The decision making process 120
 - 5.1.2 The formal data of the decision problem 123
 - 5.1.3 The decision aiding process 125
 - 5.2 Models of apparent preferences 128
 - 5.2.1 Pairwise “*at least as good as*” situations 128
 - 5.2.2 Aggregating per viewpoint or per jury member 131
 - 5.2.3 Aggregating into a global “*outranking*” statement 135
 - 5.3 Rebuilding the best poster recommendation 138
 - 5.3.1 Exploiting the CONDORCET graph 139
 - 5.3.2 The RUBIS best choice method 143
 - 5.3.3 Robustness analysis 145
 - References 155
- Editors’ comments on “The EURO 2004 Best Poster Award”** 165
 References 167
- 6 Multicriteria Evaluation-Based Framework for Composite Web Service Selection** 169
 Salem Chakhar, Serge Haddad, Lynda Mokdad, Vincent Mousseau and Samir Youcef
 - 6.1 Introduction 170
 - 6.2 Related work 171
 - 6.3 Extended Web services architecture 172
 - 6.3.1 Conventional Web services architecture 172
 - 6.3.2 Proposed Web services architecture 173
 - 6.4 Functional architecture of MEC 174

6.4.1	Identification of QoS evaluation criteria	175
6.4.2	Construction of compositions	176
6.4.3	Partial evaluation of compositions	176
6.4.4	Definition of preference parameters	176
6.4.5	Multicriteria classification	176
6.5	Constructing potential composite Web services	177
6.6	Evaluation of compositions	181
6.7	Multicriteria classification of compositions	189
6.8	Implementation issues	191
6.8.1	Prototype architecture	191
6.8.2	Presentation of the jUDDI registry	192
6.8.3	Extension of the jUDDI registry	192
6.9	Illustrative application	193
6.10	Discussion	196
6.11	Conclusion	197
	References	199
	Editors' comments on "Multi-Criteria Evaluation-Based Framework for Composite Web Services"	203
	References	204
7	Site selection for a university kindergarten in Madrid	205
	Tommi Tervonen, Gabriela Fernández Barberis, José Rui Figueira and María Carmen Escribano	
7.1	Introduction	205
7.2	SMAA-III	207
7.3	Case study	208
7.4	Discussion	213
7.5	Conclusions	214
	References	215
	Editors' comments on "Site selection for a university kindergarten in Madrid"	219
	References	220
8	Choosing a cooling system for a power plant in Belgium	221
	Marc Pirlot, Jacques Teghem, Berthold Ulungu, Léon Duvivier, Pierre Bulens and Coralie Goffin	
8.1	Introduction	221
8.2	Formulation of the problem by the working group	222
8.2.1	The alternatives	223
8.2.2	The decision <i>problématique</i>	223
8.2.3	Points of view and indicators	224
8.2.4	Assessment procedure	225

8.2.5	Relative importance of the criteria	227
8.2.6	Assessments obtained from the experts	228
8.3	Weighted sum approach	228
8.3.1	Hypotheses on the cost criterion	229
8.3.2	Scores of the alternatives under the various hypotheses on cost	231
8.3.3	Aggregating the experts scores	234
8.3.4	Conclusion for the weighted sum approach	237
8.4	Outranking approach	238
8.4.1	Applying ELECTRE II to individual experts judgments	239
8.4.2	Obtaining global rankings in the outranking approach	240
8.4.3	Applying ELECTRE II to aggregated judgements	241
8.4.4	Sensitivity analysis	244
8.4.5	Other path to outranking	246
8.5	Conclusions	249
	References	253
Editors' comments on "Choosing a cooling system for a power plant in Belgium"		
		259
	References	260
9	Participative and multicriteria localization of wind farm projects in Corsica island: decision aid process and result	263
	Pascal Oberti and Christophe Paoli	
9.1	Introduction	263
9.2	Context of the study and decision aid process	265
9.2.1	Decision problem and actors	265
9.2.2	General structure of the decision aid process	267
9.3	Actions set and criteria family	268
9.3.1	Simulated projects of wind farms	268
9.3.2	Criteria of evaluation	271
9.4	Multiple criteria evaluation and wind farm project recommendations	275
9.4.1	Performance table	276
9.4.2	Thresholds on criteria	276
9.4.3	Relative importance of criteria	277
9.4.4	Outranking aggregation and recommendations	278
9.5	Comments on the case study	280
9.6	Conclusion and enlargements	281
	References	283
Editors' comments on "Participative and multicriteria localization of wind farm projects in Corsica island"		
		291
	References	292

10	Multi-Criteria Assessment of Data Centers Environmental Sustainability	295
	Miguel Trigueiros Covas, Carlos A. Silva and Luis C. Dias	
10.1	Introduction	295
10.2	Sustainability Assessment	297
10.3	Data Center Metrics	298
10.4	A New Metric: TRUE	301
10.5	A Framework to Assess the Data Center Environmental Performance	303
10.5.1	Criteria	304
10.5.2	Criteria Evaluation	304
10.5.3	The ELECTRE TRI Method as the Evaluation Tool	306
10.5.4	Model Parameters	307
10.6	Application of the Model	310
10.6.1	Criteria Evaluation	310
10.6.2	Data Center Environmental Sustainability Performance Results	311
10.7	Conclusions	313
10.8	Acknowledgments	315
	References	317
	Editors' comments on "Multi-Criteria Assessment of Data Centers' Environmental Sustainability"	321
11	The cost of a nuclear-fuel repository: A criterion valuation by means of fuzzy logic	325
	Pierre Louis Kunsch and Monique Vander Straeten	
11.1	Introduction	325
11.2	Case study: Budgeting a nuclear-fuel repository	326
11.2.1	Technical Background	326
11.2.2	Principles of the valuation	328
11.2.3	Technology factors	329
11.2.4	Project factors	331
11.2.5	Dynamic aspects in PERT network	334
11.3	Aggregation of expert opinions with fuzzy logic	334
11.3.1	The principles of Fuzzy Inference Systems (FIS) for the analysis	334
11.3.2	Unconditional proxy valuation <i>FIS</i> (1)	337
11.3.3	Conditional intermediate valuation <i>FIS</i> (2)	338
11.3.4	Conditional final valuation <i>FIS</i> (3)	340
11.3.5	The <i>FIS</i> software	341
11.4	Procedure and results of the repository case study	342
11.4.1	The preliminary settings and the expert elicitation process	342
11.4.2	Results	344
11.5	Experience gathered through practical use	345

11.6	Conclusions	347
	References	349
Editors' comments on "The cost of a nuclear-fuel repository"		351
	References	353
12	Assessing the response to land degradation risk: the case of the Loulouka catchment basin in Burkina Faso	355
	Stéphane Aimé Metchebon Takougang, Marc Pirlot, Samuel Yonkeu and Blaise Some	
12.1	Introduction	355
12.2	Context of the case study and decisional approach	356
12.2.1	The context	356
12.2.2	Decisional approach	357
12.2.3	Decision aiding process scheme in the context of territorial management	359
12.3	Structuring the problem	361
12.3.1	Formulation of the problem	361
12.3.2	Identification of actors	361
12.3.3	Construction of the set of alternatives	362
12.3.4	Identification of criteria and indicators	363
12.3.5	Construction of principles and criteria	363
12.3.6	Construction of indicators	364
12.4	Sorting the spatial units in categories	366
12.4.1	Requirements for the application of ELECTRE TRI	367
12.4.2	Setting the parameters of the ELECTRE TRI method	369
12.5	Validation and exploitation of the results	372
12.5.1	First validation round	373
12.5.2	Second validation round	374
12.5.3	Robustness of the assignments	374
12.5.4	Assignment to categories by means of a value function model	376
12.5.5	Formulating conclusions and recommendations	387
12.5.6	Taking into account the "Elementary Needs" principle	389
12.6	Conclusion	390
12.6.1	Putting the case study in perspective	390
12.6.2	Facilitating the decision aiding process	391
	References	395
Editors' comments on "Assessing the response to land degradation risk in the Loulouka basin"		413
	References	415

13 Coupling GIS and Multi-criteria Modeling to support post-accident nuclear risk evaluation	417
Catherine Mercat-Rommens, Salem Chakhar, Eric Chojnacki and Vincent Mousseau	
13.1 Nuclear risk management and the PRIME project context	418
13.2 Methodology of evaluating the post-accident impact on the area ..	420
13.2.1 Managing the consequences of a nuclear accident	420
13.2.2 Methodology for supporting post-accidental decisions ..	421
13.3 Application and results: using the data and results obtained	423
13.3.1 Elaborating the multi-criteria evaluation matrix	423
13.4 Results	434
13.4.1 Radio-ecological vulnerability	434
13.4.2 Global vulnerability	437
13.4.3 The approach's advantages and limitations and prospects	440
13.5 Conclusion	440
References	443
Editor's comments on "Coupling GIS and Multi-criteria Modeling to support post-accident nuclear risk evaluation"	445
References	447
14 A multicriteria spatial decision support system for hazardous material transport	449
A. Luè and A. Colorni	
14.1 Introduction	450
14.2 Philosophy and structure of the DSS	451
14.3 The risk assessment model	454
14.4 The route selection model: a multi-objective problem	455
14.5 The case study	459
14.6 Conclusions and future challenges	460
References	467
Editors' comments on "A multi-criteria decision support system for hazardous material transport in Milan"	471
References	473
15 Rural Road Maintenance in Madagascar The GENIS project	475
Alexis Tsoukiàs and Herimandimbiniaina Ralijaona	
15.1 Introduction	475
15.2 Problem Situation	477
15.3 Problem Formulation	479
15.4 Evaluation Model	480
15.4.1 Alternatives	480
15.4.2 Dimensions and Measurement Scales	481

15.4.3	Criteria	482
15.4.4	Aggregation Procedure	485
15.5	Pilot Study	485
15.6	Feedback	488
15.7	Conclusions	490
	References	493
Editors' comments on "Rural Road Maintenance in Madagascar"		497
	References	499
16	On the use of a multicriteria decision aiding tool for the evaluation of comfort	501
	Meltem Öztürk, Alexis Tsoukiàs and Sylvie Guerrand	
16.1	Problem definition	501
16.2	Comfort Components	503
16.3	Model	507
16.4	Value scales for seating comfort	509
16.5	ELECTRE TRI as the evaluation tool of our study	510
16.5.1	Why ELECTRE TRI?	511
16.6	Decision parameters	512
16.6.1	Importance parameters	513
16.6.2	Thresholds	513
16.6.3	Limit profiles	514
16.6.4	Aggregation of sub-categories	514
16.7	Examples	518
16.7.1	Assignment of Offer 1 to the class <i>normal seating comfort</i>	518
16.7.2	Assignment of Offer 2 to the class <i>good seating comfort</i>	518
16.7.3	Assignment of Offer 3 to two different classes <i>not bad seating comfort</i> and <i>good seating comfort</i>	519
16.8	Conclusion	519
	References	523
Editors' comments on "On the use of a multicriteria decision aiding tool for the evaluation of comfort"		529
	References	530
17	An MCDA approach for evaluating hydrogen storage systems for future vehicles	533
	Florent Montignac, Vincent Mousseau, Denis Bouyssou, Mohamed Ali Aloulou, Benjamin Rousval and Sébastien Damart	
17.1	Introduction	534
17.2	General framework of the study: the STORHY European Project	535
17.2.1	The STORHY European Project	535

17.2.2	The subproject Evaluation	535
17.2.3	Focus on the evaluation of the technical performance	538
17.3	MACBETH: motivation and brief description	539
17.3.1	The choice of MACBETH	539
17.3.2	General principles of MACBETH method	540
17.3.3	Implementation	541
17.3.4	Extension of the approach	550
17.4	Comments on the case and on the decision aiding process	552
17.4.1	The specific context of a European research project	552
17.4.2	The interest of MACBETH approach	553
17.4.3	Multicriteria evaluation in a multi-actor R&D context	553
	References	555
Editors' comments on "An MCDA approach for evaluating hydrogen storage systems for future vehicles"		565
18	An MCDA approach for Personal Financial Planning	569
	Oliver Braun and Marco Spohn	
18.1	Overview	569
18.2	Problem structuring	573
18.3	Evaluation	575
18.4	Process-related aspects	584
18.4.1	AHP phase	586
18.4.2	MILP phase	587
18.5	Results	592
	References	595
Editors' comments on "an MCDA approach for Personal Financial Planning"		599
	References	600
19	A Multicriteria Approach to Bank Rating	601
	Michael Doumpos and Constantin Zopounidis	
19.1	Introduction	601
19.2	Problem context and multicriteria methodology	602
19.2.1	Relative evaluation	603
19.2.2	Absolute evaluation	607
19.2.3	Sensitivity analysis	607
19.2.4	Monte Carlo simulation	609
19.2.5	Implementation	610
19.3	Application	611
19.3.1	Data and evaluation parameters	611
19.3.2	Results	614
19.4	Conclusions	617

Contents	xix
References	619
Editors' comments on "A multi-criteria approach to bank rating"	625
References	628
Part III MCDA process support tools	
20 XMCDA: an XML-based encoding standard for MCDA data	633
Sébastien Bigaret and Patrick Meyer	
20.1 Introduction	633
20.2 A first cup of XMCDA	634
20.2.1 Technical aspects and choices for XMCDA	634
20.2.2 Conventions	636
20.2.3 Three essential XMCDA types	638
20.2.4 Elementary XMCDA tags	640
20.3 XMCDA encoding of MCDA data	642
20.3.1 Definition of alternatives, criteria, categories and performances	643
20.3.2 Advanced information and preferences on alternatives, criteria and categories	646
20.3.3 Program specific data	653
20.4 Illustration of XMCDA in practice	654
20.4.1 XMCDA encoding of Thierry's car selection problem	655
20.5 Conclusion	658
References	659
21 Supporting the MCDA process with the diviz workbench	661
Sébastien Bigaret and Patrick Meyer	
21.1 Introduction	661
21.2 diviz for dummies	663
21.2.1 Use of diviz	663
21.2.2 Resources used by diviz	667
21.3 diviz to support the MCDA process	668
21.3.1 Analysis of the problem and the underlying data	670
21.3.2 Preference elicitation	673
21.3.3 The aggregation phase	675
21.3.4 Analysis of the results	677
21.4 Concluding remarks	678
References	681
Index	683

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Chapter 1

Introduction

Raymond Bisdorff, Luis C. Dias, Patrick Meyer, Vincent Mousseau and Marc Pirlot

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 statement¹).
 - 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 XMCD 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 a problem	Condorcet method and RUBIS	Scientific association	Jury members	An existing software
Ch.6 Composite Service Selection	Web Internet services	France	Framework	Choice sorting)	(by ELECTRE TRI	Consumer	An individual	A prototype was developed
Ch.7 Site selection for a kindergarten	Education	Spain	Analysis of a problem	Choice ranking)	(by 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 ranking)	(by 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 ranking)	(by 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 terminating value)	(defuzzy inference a	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 a problem	ELECTRE TRI	Public administration	Group of stakeholders	A SDSS was developed
Ch.14 Hazardous material transport	Energy/ environment, transportation	Italy	Proof of concept	Choice ranking)	(by Weighted sum	Public administration	Group of experts	SDSS (custom adapted)
Ch.15 Rural Road Maintenance	Main-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 ranking)	(by 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 a problem	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.