Strategic Decision Making

Multiobjective Decision Analysis with Spreadsheets

Revised Edition

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To Lisa and Susan

Contents

Preface

This book presents methods for strategically making decisions using quantitative, spreadsheet-based, decision analysis methods. The intended audience is anyone responsible for decision making in an organizational setting, and the book provides a framework for thinking about decisions strategically, as well as practical tools that the reader can immediately apply. The book is suitable for use in classes on decision making, as well as for self-study. This revised edition corrects minor errors in the original version published by Duxbury Press and adds Supplemental Notes at the end of this Preface. There are no other changes except for small formatting changes to some figures and citations in the margin at appropriate places to the corresponding Supplemental Notes.

Rules of thumb, intuition, tradition, and simple financial analysis are often no longer sufficient for addressing such common decisions as make-versus-buy, facility site selection, and process redesign. In general, the forces of competition are imposing a need for more effective decision making at all levels in organizations. The ongoing restructuring of businesses and other organizations increases the usefulness of the material in this book for a wide range of managers, analysts, and engineers. Traditionally, strategic decisions involving multiple competing objectives and significant uncertainties have been considered primarily the concern of top executives. However, with the ongoing emphasis on downsizing and flattening organizations, individuals at lower levels in organizations must be concerned with such tradeoffs as cost versus quality, cost versus timeliness, or market share versus short-term return on investment.

The methods in this book have been applied for five decades, and they have a demonstrated capability to improve decision making. The methods have traditionally been considered advanced, in part because early presentations were framed in a mathematical terminology that is not familiar to many managers, and in part because early implementations of the methods required specialized software. This book brings the methods to a broader audience by explaining the intuitive basis for the methods, as well as how to implement them using spreadsheets.

Purpose I wrote this book to make strategic decision making methods accessible for those who are making the decisions. The approaches in this book can help you to improve your decision making processes. The decision structuring methods in the first three chapters provide a framework for thinking about virtually all decisions ranging from those that are relatively tactical to corporate strategy. Numerous examples are included to give you a starting point for your own decision analyses. Later chapters of the book present detailed procedures for quantitatively analyzing decisions using spreadsheets. The methods are based on intuitively appealing principles, which are discussed as the methods are presented. There are no mysterious procedures. You can understand, implement, and explain these methods without the need for specialized consultants or software.

Focus and approach The focus is on decisions where there are multiple competing objectives that require consideration of tradeoffs among these objectives. This book brings the tools to analyze these decisions to a wider range of decision makers through the use of spreadsheet methods. The approach is to provide a structured, quantitative process for making such decisions by using spreadsheet analysis methods. We take the view that decisions should be made *strategically*, that is, in a skillful manner that is adapted to the ends that the decision maker wishes to achieve. While there is probably little argument that such an approach is desirable, the methods to actually carry out this type of analysis have often been considered beyond the resources of managers below the top level in large organizations.

Audience and prerequisites The only prerequisite for much of the book is an understanding of elementary algebra. The sections that consider computer-based computational procedures also require an elementary understanding of electronic spreadsheets. Microsoft Excel is used in the book, including some use of Visual Basic for Applications. However, the reader does not need to be familiar with Visual Basic or to learn anything about that programming language to apply the methods.

Classes using the material in this book have included students in business administration, engineering, health policy and administration, and public policy. Most of these students have had practical experience in business, government, or the not-for-profit sector. The quantitative and computer backgrounds of the students in each class have generally varied substantially.

Organization The book can be used in a variety of ways for either class instruction or self-study. It is self-contained and can be used for a first course in decision making which focuses on decisions with multiple objectives. It can be used in conjunction with a text such as by Robert T. Clemen and Terence Reilly's *Making Hard Decisions with Decision Tools*, Third Edition, South-Western, Cengage Learning, Mason, Ohio, 2014, in a first decision analysis course which places less emphasis on decisions with multiple objectives. It can also be used as the text for a course in multiobjective decision analysis which follows a traditional first decision analysis course.

An instructor's manual is available with solutions to the exercises.

Chapters 1, 2, and 3 address decision problem structuring (formulating). Chapter 4 addresses evaluation of alternatives with multiple objectives and no uncertainty. Chapters 5, 6, and 7 address evaluation of alternatives with uncertainty. Chapter 8 reviews procedures for analyzing resource allocation decisions with multiple objectives in the face of budget or other constraints. Chapter 9 presents theory that underlies the methods in earlier chapters. You do not have to understand this chapter to make practical use of the methods in the earlier chapters.

The appendices provide supplemental and background material. Appendix A presents a case that illustrates the application of the methods in Chapters 2, 3, and 4. Appendix B presents scenario planning approaches to analyzing decisions with uncertainty. These approaches can be used in conjunction with, or as an alternative to, the probability analysis methods in Chapters 5, 6, and 7. Appendix C presents a transcript of a probability elicitation session with a senior executive. Appendix D presents basic concepts of conditional probabilities, including use of influence diagrams and decision trees.

Chapter 9 is more abstract and requires somewhat more technical background than the other chapters and appendices. It can be assigned as optional reading or used as the primary reading for a more theoretical course. The material in Chapter 8 has also traditionally been considered more advanced, but with the current general availability of spreadsheet optimization features, these methods are now more widely used.

The latter parts of Chapters 4, 6, and 7, as well as Chapter 8, make use of electronic spreadsheets, and readers studying this material need to be familiar with elementary spreadsheet concepts. Some specific features of Excel are used, although the approaches can be translated to other advanced spreadsheets. The Appendix A case study does not specifically require spreadsheet computations, but the calculations needed to complete the case will be tedious without a spreadsheet. A reader wishing to understand the methods presented in this book but not how to implement them can skip the spreadsheet material without loss of continuity. Some readers may wish to use specialized multiobjective decision analysis software, and an appropriate package is *Logical Decisions for Windows*, available at https://www.logicaldecisionsshop.com/catalog/.

All chapters include both Review Questions and Exercises. While either of these can be assigned as homework, the review questions are more open-ended and sometimes do not have a unique answer. Thus, these questions may be more suitable for in-class review purposes.

The diagram following this preface shows the primary precedence relationships among the chapters and appendices. In addition, Section 8.4 requires background provided in Section 7.7.

For readers who are familiar with multiobjective decision analysis methods, note that this book uses multiattribute value and utility analysis methods, including probabilistic analysis of decisions with uncertainty. A measurable value approach is taken, although an instructor who wishes to take a more traditional approach can do that in a straightforward manner using the material in the book.

Corrections Corrections have been made in this revised edition for the following errors in the original edition:

Page 101: In Exercise 4.5, part iii, the last sentence was deleted ("Assume that, while you are varying this weight, the ratio of the other two weights remains constant.") because there are only two evaluation measures in this exercise.

Page 103: In Exercise 4.7, six lines from the bottom of the page, "increasing accuracy from 95 percent to 99 percent" was changed to "increasing uptime from 95 percent to 99 percent."

Page 117: In the seventh line from the bottom of the page, "the uncertainty quantity" was changed to "the uncertain quantity."

Page 161: In equation (7.2), x_i was changed to x_1.

Page 164: In the first line of equation (7.3), ρ without a subscript was changed to ρ_m.

Page 165: In the first line of equation (7.5), the rightmost right parenthesis was deleted.

Page 166: In the third line of the equation on this page (which begins with a plus sign), the left bracket and the 0.67 that follows this bracket were deleted.

Page 242: In the second paragraph, second line, "that we that" was changed to "that we have."

Page 258: In the left hand side of equation (9.41.1), $u(x)$ was changed to $u(x_1, x_2, \ldots, x_n)$.

Supplemental Notes Notes marked with an asterisk (*) below provide additional explanations, and I recommend that you read these with the corresponding sections of the book. The other notes provide additional technical material and references for readers who wish to examine a topic in more detail. In the main body of the book, the existence of an associated note for a particular section is indicated by [*Note *x*], or [*Note x*] in the margin, where "x" is the number of the associated note below.

**1. Page 24*: The discussion of evaluation measures in Section 2.4 does not make clear exactly which elements in a value tree (hierarchy) must have evaluation measures associated with them. From the definition of a value tree on pages 12 and 13 (especially the discussion of "layers" or "tiers" on page 13), it follows that when the performance of an alternative is specified for the evaluation considerations *most distant* from the root of the tree, then this specifies the performance of the alternative for the entire tree. Therefore, it is only necessary to develop evaluation measures for the "leaves" at the end of each "branch" of the value tree.

As an example, for the value tree shown in Figure 2.1 on page 14, it is only necessary to develop evaluation measures for software outlay; training, maintenance, and upgrades; hardware outlay; technical graphics; tables; automation and customization; interoperability; layout, editing, and formatting; long documents and proofing; marketing graphics; printing and mail merge; and interface. That is, a total of twelve evaluation measures are needed for this value tree.

Evaluation measures are not needed for purchase best value software; cost; suitability for use; production, R&D, and engineering; finance and administration; or marketing because these considerations each consist of other elements lower in the hierarchy that have evaluation measures associated with them.

2. Pages 50-51: Options analysis approaches have been applied to the type of sequencing alternatives discussed in Section 3.4. For further information, see T. W. Faulkner, "Applying 'Options Thinking' to R&D Valuation," *Research Technology Management*, Vol. 39, No. 3, pp. 50-56 (May-June 1996). For a more theoretical discussion, see J. E. Smith and R. F. Nau, "Valuing Risky Projects: Option Pricing Theory and Decision Analysis," *Management Science*, Vol. 41, No. 5, pages 795-816 (May 1995).

**3. Pages 54-55*: The example in Section 4.1 includes two evaluation measures with constructed scales. For both of these, the data in Table 4.1 includes cases where the scores are intermediate between levels for the evaluation measure scales that are defined on page 54. There is no discussion about how such intermediate scores should be determined or what these intermediate scores mean.

An intermediate score means that the alternative with the intermediate score has a single dimensional value that is intermediate between the values for the two defined evaluation measure scores on either side of the intermediate score. For example, the score of 0.5 for the Low Quality/Low Cost alternative on the Productivity Enhancement evaluation measure means that this alternative has a single dimensional value for Productivity Enhancement that is intermediate between the values for the zero and one levels defined on page 54. More specifically, since the score of 0.5 is exactly half way between the defined levels of zero and one, then the Low Quality/Low Cost alternative has a single dimensional value on Productivity Enhancement that exactly half way between the single dimensional values for the zero and one levels. A calculation procedure to determine single dimensional values is presented in Sections 4.2 and 4.3.

**4. Pages 68-72*: Section 4.4 does not address how a hierarchical value structure is used in determining weights. The procedure does not explicitly use the hierarchical structure when determining weights. That is, the various evaluation measures are used in the procedure to determine weights without considering which layer each evaluation measure belongs to in the value tree.

Therefore, this procedure does not require determining weights for evaluation considerations that do not have evaluation measures associated with them. For example, in the value tree shown in Figure 2.1 (page 14), it is not necessary to determine weights for cost; suitability for use; production, R&D, and engineering; finance and administration; or marketing. If you wish to associate weights with these considerations, then a reasonable method to do this is to add up the weights for the evaluation measures below each consideration. As an example, a weight could be assigned to production, R&D, and engineering that is the sum of the weights for technical graphics; tables; and automation and customization.

5. Pages 68-72: A simplified version of the weight assessment procedure presented in Section 4.4, called the Swing Weight Matrix Method, is presented in the context of specific applications by P. L. Ewing Jr., W. Tarantino, and G. S. Parnell, "Use of Decision Analysis in the Army Base Realignment and Closure

(BRAC) 2005 Military Value Analysis," *Decision Analysis*, Vol. 3, No. 1, pp. 33-49 (March 2006), and T. Trainor, G. S. Parnell, B. Kwinn, J. Brence, E. Tollefson, and P. Downes, "The US Army Uses Decision Analysis in Designing Its US Installation Regions," *Interfaces*, Vol. 37, No. 3, pp. 253-264, May-June 2007.

Other procedures for determining weights explicitly consider the hierarchical structure of the value tree. For analysis of differences that can result from using different weight assessment procedures, see: 1) W. G. Stillwell, D. von Winterfeldt, and R. S. John, "Comparing Hierarchical and Nonhierarchical Weighting Methods for Eliciting Multiattribute Value Models," *Management Science*, Vol. 33, No. 4, pp. 442-450 (April 1987), and 2) M. Weber, R. Eisenfhr, and D. von Winterfeldt, "The Effects of Splitting Attributes on Weights in Multiattribute Utility Measurement," *Management Science*, Vol. 34, No. 4, pp. 431-445 (April 1988).

6. Pages 75-96: If you are still using Excel 97, which was released in 1996, there is a display bug in Excel 97 that impacts some spreadsheets in Sections 4.7 and 4.8. This is a display bug rather than a recalculation bug, and manually recalculating the worksheet does not correct the problem. You can correct the screen display by taking some action that requires the worksheet to be redisplayed. For example, switch to another worksheet and then switch back.

**7. Page 78*: The discussion of the arguments for the piecewise linear single dimensional value function ValuePL(x, X-list, V-list) does not explicitly state the order in which the elements of X-list and V-list should be entered. These should be entered so that the elements of X-list are monotonically increasing regardless of whether the single dimensional value function is monotonically increasing, monotonically decreasing, or non monotonic. For example, suppose a monotonically decreasing piecewise linear single dimensional value function is specified by three evaluation measure levels 10, 16, and 20, with corresponding single dimensional values 1, 0.7, and 0. Then the X-list should be in the order 10, 16, and 20, and the V-list should be in the order 1, 0.7, and 0. ValuePL does not do much error checking, and it will usually not detect an incorrect entry order for arguments.

**8. Page 80*: The instructions for inserting a Visual Basic module into an Excel workbook are outdated. In recent versions of Excel, first add the Developer tab to your menu if it is not already showing using the following menu sequence: File, Options, Customize Ribbon, and then check the Developer box and OK. The Developer tab will now show on the Excel menu. Select the Developer tab and double-click on Visual Basic, which will open the Visual Basic Editor.

To create a Visual Basic module, select the following menu sequence in the Visual Basic Editor: Insert, Module. In the window that is opened, enter the code shown in Figure 4.5 on page 81. To return to the Excel spreadsheet, select File on the Visual Basic Editor menu bar and then "Close and Return to Excel."

The Visual Basic module you have created will not appear among the worksheet tabs at the bottom of the Excel window, but this module will automatically be saved with your spreadsheet when you select an Excel file type that allows such modules, such as "Excel Macro-Enabled Workbook (*.xlsm)." If you try to save the workbook with another file type, you will be warned that your Visual Basic macros will not be saved. When you open a workbook with a Visual Basic module, you may be warned that "Macros have been disabled," and then you will have to click the button labeled "Enable Content" to allow the Visual Basic macros to work.

9. Pages 107-116: The historical development of ideas about uncertainty is presented in P. L. Bernstein, *Against the Gods: The Remarkable Story of Risk*, Wiley, New York, 1996. See especially Chapter 16, "The Failure of Invariance," which contains additional examples of reasoning difficulties about uncertainty.

10. Page 138: The accuracy of the exponential utility function as an approximation to other utility functions is studied in C. W. Kirkwood, "Approximating Risk Aversion in Decision Analysis Applications," *Decision Analysis*, Vol. 1, No. 1, pp. 55-72 (March, 2004).

11. Pages 138-141: The accuracy of several methods for determining utilities is studied in H. Bleichrodt, J. M. Abbellan-Perpian, J. L. Pinto-Prades, and I. Mendez-Martinez, "Resolving Inconsistencies in Utility Measurement Under Risk: Tests of Generalizations of Expected Utility," *Management Science*, Vol. 53, No. 3, pp. 469-482 (March 2007).

12. Pages 138-143: An application using exponential utility functions is presented in M. R. Walls, G. T. Morahan, and J. S. Dyer, "Decision Analysis of Exploration Opportunities in the Onshore US at Phillips Petroleum Company," *Interfaces*, Vol. 25, No. 6, pp. 39-56 (November-December 1995).

13. Pages 142-143: The impact of organizational size on risk attitude is examined in M. R. Walls and J. S. Dyer, "Risk Propensity and Firm Performance: A Study of the Petroleum Exploration Industry," *Management Science*, Vol. 42, No. 7, pp. 1004-1021 (July 1996). Their empirical work indicates that risk tolerance increases with increasing organizational size, but that the increase is not in the simple linear manner indicated by Howard's rules of thumb.

See also J. Eric Bickel, "Some Determinants of Corporate Risk Aversion," *Decision Analysis*, Vol. 3, No. 4, pp. 233-251 (December 2006) for further consideration of rationales for corporate attitudes toward risk taking. Bickel concludes that he is unable to fully support the degree of corporate risk aversion reported in the decision analysis literature.

14. Pages 147, 149: The spreadsheets in Figures 6.4 and 6.5 can be simplified using the Excel SUMPRODUCT function, which removes the need for a "product" column in the spreadsheets.

15. Pages 200-206: The theoretical basis for the benefit/cost approach in Section 8.1 is presented in H. Everett III, "Generalized Lagrange Multiplier Method for Solving Problems of Optimum Allocation of Resources," *Operations Research*, Vol. 11, No. 3, pp. 399-417 (May/June 1963). See also A. Charnes and W. W. Cooper, "A Note on the 'Fail-Safe' Properties of the 'Generalized Lagrange Multiplier Method,'" *Operations Research*, Vol. 13, No. 4, pp. 674-677 (July/August 1965), and H. Everett, III, "Comments on Preceding Note," *Operations Research*, Vol. 13, No. 4, pp. 677-678 (July/August 1965).

**16. Pages 200-211*: The analysis procedures in Sections 8.1 and 8.2 implicitly assume that the value of *not* selecting any project is zero. (Another way of saying this is that not selecting a project is assumed to be equivalent in a value sense to selecting a project that has the worst possible score on each of the evaluation measures.) The following example shows how to analyze decisions where *not* selecting a project has some value.

Suppose you own three fast food restaurants that are run down but functional. You have a budget of 250 thousand dollars to renovate one or more of the restaurants. You develop evaluation measures and a multiobjective value function to score the current conditions of the restaurants and their conditions if they were renovated. Assume the cost of renovating each restaurant, as well as the renovated and current values and the value increment (Renovated Value minus Current Value) for renovating each restaurant, are as follows:

Project	Cost	Value		
		Renovated	Current	Increment
Restaurant 1	200	0.55	0.30	0.25
Restaurant 2	120	0.40	0.25	0.15
Restaurant 3	100	0.30	0.25	0.05

By inspection, you can see that the two competitive combinations of renovation projects that could be completed within the available budget are to 1) renovate only Restaurant 1, or 2) renovate both Restaurants 2 and 3. Assuming that the values of projects add, then it may appear that the combination of renovating Restaurants 2 and 3 should be selected since this has a renovated value of $0.40 + 0.30 = 0.70$ versus a renovated value of 0.55 for Restaurant 1.

However, this is not the complete story. The fourth column of the table shows the current values of the three restaurants, and the right-most column shows the difference between the renovated and current values. The value increment from renovating Restaurant 1 is greater than the sum of the value increments from renovating Restaurants 2 and 3 (0.25 versus $0.15 + 0.05 = 0.20$). It is shown in Note 17 that *value increments* should be used in selecting the best combination of projects, and hence Restaurant 1 should be renovated.

If not selecting a particular project has a cost, then that cost needs to be taken into account. This does not change the value associated with selecting a particular set of projects, but it might make some combinations of projects infeasible. This is discussed further in Note 17.

17. Pages 200-211: This note demonstrates that when values add, as in the Note 16 example, project portfolios where not selecting a project has a non-zero value can be analyzed by subtracting the value of not selecting each project from the value of selecting it, as was presented in the Note 16 example.

Let $a_i, i = 1, 2, \ldots, N$ be the set of N possible projects to include in a portfolio, where v_i is the value gained by including a_i in the portfolio, and v_i^0 is the value gained by not including a_i in the portfolio. Let I_i be a binary variable that indicates whether or not a_i is included in the portfolio, where $I_i = 1$ means the project is included, and $I_i = 0$ means it is not included.

This portfolio decision can be analyzed by considering not including a_i in the portfolio to be an project just as including a_i is a project. Because a_i cannot both be included and not included in the portfolio at the same time, and one of these two possibilities must be included in any feasible portfolio, therefore it must be true that the binary variables for the possibilities of including and not including a_i always sum to one. Hence, assuming that values add, the total value for any possible portfolio is

$$V = \sum_{i=1}^{N} [v_i I_i + v_i^0 (1 - I_i)] = \sum_{i=1}^{N} (v_i - v_i^0) I_i + \sum_{i=1}^{N} v_i^0$$

However, the term

$$\sum_{i=1}^{N} v_i^0$$

is equal to a constant, and therefore can be dropped from the value function without changing the ranking of different possible portfolios. Thus, using

$$\sum_{i=1}^{N} (v_i - v_i^0) I_i$$

as the value function for the portfolio will give the correct ranking of portfolios.

This shows that subtracting the value v_i^0 of not selecting a project from the value v_i of selecting the project in the value analysis for a portfolio will give the correct ranking of portfolios.

If there is a cost for not selecting a project, then that cost needs to be taken into account. Suppose the cost of selecting a_i is c_i and the cost of not selecting a_i is c_i^0, and the total available budget is C_T. Then the cost constraint is

$$\sum_{i=1}^{N} [c_i I_i + (1 - I_i) c_i^0] \leq C_T$$

Rearranging terms, this can be written as

$$\sum_{i=1}^{N} (c_i - c_i^0) I_i \leq C_T - \sum_{i=1}^{N} c_i^0$$

Therefore, a correct analysis is to set the cost constraint by 1) subtracting the cost c_i^0 of not selecting each alternative from the cost c_i of selecting that alternative in the terms of the cost expression, and 2) subtracting the total cost $\sum_{i=1}^{N} c_i^0$ of not selecting *all* the alternatives from the total available budget C_T.

This is discussed further in R. T. Clemen and J. E. Smith, "On the Choice of Baselines in Multiattribute Portfolio Analysis: A Cautionary Note," *Decision Analysis*, Vol. 6, No. 4, pp. 256-262 (December 2009).

**18. Pages 206-211*: Section 8.2 (page 210) notes that Excel Solver may not find the very best possible solution with its default option settings. Solver notation for some options has changed since the original version of this book was published, and the instructions in Section 8.2 to avoid this problem are not correct for recent versions of Excel. The avoid this problem in recent Excel versions, examine two settings under "Options" in the Solver Parameter dialog: 1) make sure the "Ignore Integer Constraints" box is *not* checked, and 2) make sure the "Integer Optimality (%)" setting is set to 0 (zero). If the "Integer Optimality (%)" setting is greater than zero, a warning will be displayed after you run Solver that "It is possible that better integer solutions exist." (This setting is greater than zero by default because it can take a long time to find the very best solution for very large problems. This is not an issue for problems of the size considered in Section 8.2.)

Also, as noted in Section 8.2, the example in this section has a linear structure, and there is a particularly efficient method to solver linear problems. You tell Solver to use that method in recent versions of Excel by setting "Select a Solver Method" to "Simplex LP."

The Excel Solver example in Section 8.2 uses *decision variables* that can be either zero, if a project is *not* included in the portfolio, or one, if the project *is* included in the portfolio. The requirement that each of these variables can only be zero or one is specified by three constraints in Section 8.2: 1) the variable must be an integer, 2) the variable must be less than or equal to one, and 3) the variable must be greater than or equal to zero. In recent versions of Excel Solver, a single constraint can be used to specify that a decision variable can only be zero or one, which is done by specifying that the variable must be *binary*. Directly specifying binary variables can simplify the Solver model specification and make it easier to understand. This is shown by Figure P.1, which is the Solver answer report for the Section 8.2 example using binary variable specifications. This corresponds to the much longer answer report shown in Section 8.2, Figures 8.7a and 8.7b. Specifically, the single bottom line in Figure P.1 replaces the last thirty lines in Figure 8.7b.

**19. Page 216*: The Section 8.4 example does not have a linear structure, and therefore in recent versions of Excel you should set the Solver option "Select a Solving Method" to "GRG Nonlinear" before solving for the best solution.

20. Page 241: In addition to the Dyer and Sarin (1979) reference in the last paragraph on page 241, see J. M. Deichtmann and F. Sainfort, "On the Difference Between the Cardinalities of Measurable Value Functions and von Neumann-Morgenstern Utility Functions," *Operations Research*, Vol. 45, No. 2, pp. 307-308 March/April 1997). That paper presents an additional technical condition that is needed for the measurable value function decomposition theorem to be valid.

21. Pages 249-259: Several proofs on those pages implicitly assume the outcome space is a whole product set over the evaluation measures. Situations where the outcome space is a subset of a product space are investigated in F. Sainfort and J. M. Deichtmann, "Decomposition of Utility Functions on Subsets of Product Sets," *Operations Research*, Vol. 44, No. 4, pp. 609-616 (July/August 1996).

22. Pages 259-260: Another reference comparing the Analytic Hierarchy Process with multiattribute value approaches is A. A. Salo and Raimo P. Hamalainen, Objective Cell (Max)

Cell	Name	Original Value	Final Value
$C$13	Total: Value	0.77	0.77

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$3	P1.1 Decision	1	1	Binary
$B$4	P1.2 Decision	0	0	Binary
$B$5	P1.3 Decision	0	0	Binary
$B$6	P2.1 Decision	0	0	Binary
$B$7	P2.2 Decision	0	0	Binary
$B$8	P2.3 Decision	1	1	Binary
$B$9	P3 Decision	0	0	Binary
$B$10	P4 Decision	1	1	Binary
$B$11	P5 Decision	1	1	Binary
$B$12	P6 Decision	0	0	Binary

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$13	Total: YR1	6.5	$D$13<=$D$14	Not Binding	3.5
$E$13	Total: YR2	8	$E$13<=$E$14	Not Binding	2
$F$13	Total: YR3	10	$F$13<=$F$14	Binding	0
$G$13	Total: YR4	6	$G$13<=$G$14	Not Binding	4
$H$13	Total: YR5	2.5	$H$13<=$H$14	Not Binding	7.5
$I$13	Total: Product 1	3	$I$13>=$I$14	Not Binding	2
$J$13	Total: Product 2	1	$J$13>=$J$14	Binding	0
$K$13	Total: P1	1	$K$13<=$K$14	Binding	0
$L$13	Total: P2	1	$L$13<=$L$14	Binding	0
$B$3:$B$12=Binary					

Figure P.1 *Section 8.2 Solver answer report with binary variable specifications*

"On the Measurement of Preferences in the Analytic Hierarchy Process," *Journal of Multi-Criteria Decision Analysis*, Vol. 6, No. 6, pp. 309-319 (November 1997). There are also six discussion articles on pages 320-343 of the same issue by M. Weber; H. A. Donegan; B. Schoner, E. U. Choo, and W. C. Wedley; T. L. Saaty; V. Belton and T. Gear; and A. Stam; and a rejoinder by the authors.

23. Pages 285-298: For a detailed discussion of various approaches to scenario planning, including examples, see Gill Ringland, *Scenario Planning: Managing for the Future*, Wiley, Chichester, England, 1998.

24. Pages 291-293: For a more detailed discussion of inadvertent intrusion into the Waste Isolation Pilot Project, see Martin J. Pasqualetti, "Landscape Permanence and Nuclear Warnings," *The Geographical Review*, Vol. 87, No. 1, pp. 73-91 (January 1997).

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Craig W. Kirkwood
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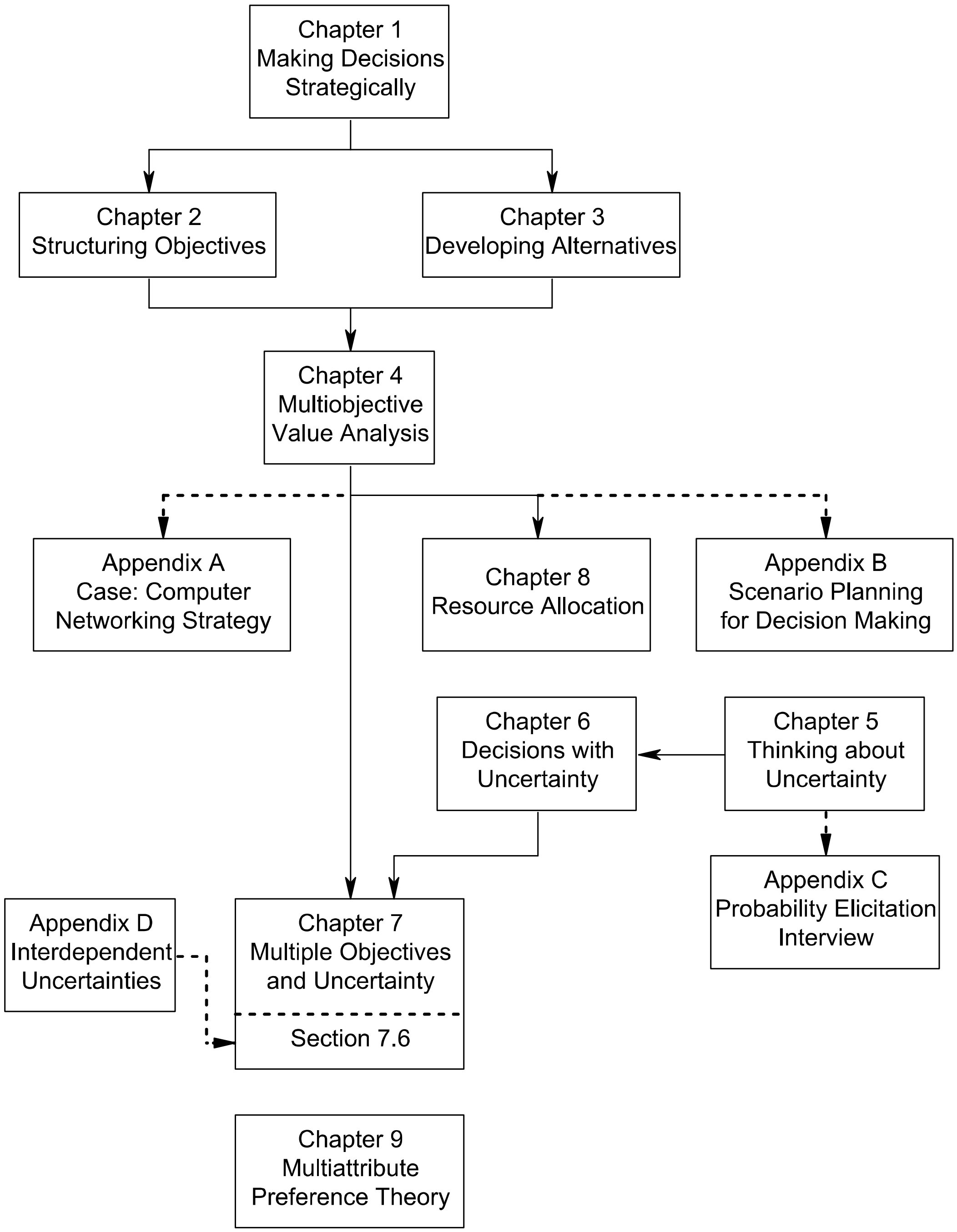
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Strategic Decision Making

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Revised Edition