

MANAGEMENT DECISION MAKING

Spreadsheet modeling,
analysis, and application

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Contents

<i>List of tables</i>	xix
<i>List of figures</i>	xxv
<i>Preface</i>	xxxiii

1 The science of managerial decision making 1

1.1	Introduction	1
1.1.1	Part I: decision making using deterministic models	2
1.1.2	Part II: decision making under uncertainty	5
1.2	Models	6
1.2.1	Stages of model development	8
1.3	Spreadsheet models	9
1.4	A lease/buy problem	11
1.4.1	Problem statement	11
1.4.2	Influence diagrams	11
1.4.3	A spreadsheet model of the lease/buy problem	13
1.4.4	Sensitivity analysis	19
1.5	What's next?	23
1.6	Problems	23
1.7	Solution to the hands-on exercise	24

Part I Decision making using deterministic models 27

2 Introduction to linear programming models 29

2.1	Formulating a decision model	30
2.1.1	General structure of decision models	31

2.1.2	MicroWorks, Inc.: a product mix problem	32
2.1.3	Model formulation	33
2.1.4	Linear programs	40
2.2	Building a linear programming model in an EXCEL worksheet	41
2.2.1	Benefits of LP Standard Form	45
2.3	Computing an optimal solution using Solver	46
2.3.1	Installing Solver	46
2.3.2	Using Solver	46
2.4	Integer versus non-integer solutions	54
2.5	Cash-for-Trash Recycling blending problem	56
2.5.1	Formulating the CTR model	57
2.5.2	Pictures and simple numerical examples: some problem formulation aids	59
2.6	The CTR spreadsheet model	60
2.7	Computing an optimal solution to the CTR problem	62
2.8	The StdFormTemplate.xls workbook	67
2.9	Trouble-shooting	68
2.9.1	Nonlinearities	68
2.9.2	No solution found	69
2.9.3	Unbounded solution	69
2.9.4	An unexpected “optimal” solution	70
2.10	The BGT Candy Company problem	70
2.10.1	The optimal solution	74
2.11	Summary	77
2.12	Problems	77
2.13	Solutions to some hands-on exercises	91

3 Developing model formulation skills 93

3.1	An overview of problem types	94
3.1.1	Static and dynamic models	96
3.2	A portfolio selection problem (how?)	97
3.2.1	Solving the portfolio selection problem	97
3.3	A cutting stock problem (how, what?)	100
3.3.1	Solving the cutting-stock problem	100
3.4	Network flow problems (what, where?)	102
3.4.1	Integer solutions	106
3.5	Captain Wise’s packing problem (what, where?)	106

3.5.1	Solving Captain Wise’s problem	107
3.6	A staff scheduling problem (what, when?)	111
3.6.1	Solving the staffing problem	112
3.7	Capital budgeting (when, what?)	113
3.7.1	Maximizing terminal net worth	114
3.7.2	Maximizing the sum of discounted cash flows	119
3.7.3	Optimality of consuming versus saving	122
3.8	A “transportation” problem (what, where?)	124
3.8.1	The LP formulation	124
3.8.2	Spreadsheet models	125
3.9	Production-inventory problems (what, when?)	127
3.9.1	Precision Products’ production planning problem	128
3.9.2	A spreadsheet model of the Precision Products problem	129
3.10	A multiple supplier problem (where, how?)	131
3.10.1	Solving Farm Implement’s supply problem	132
3.11	Disentangling the bankruptcies in the al-Manakh stock market crash	135
3.12	Problems	139
3.13	Solution to the hands-on exercise	168

4 More advanced linear decision problems 169

4.1	High Margins, Inc.	170
4.1.1	A production planning problem with backlogging	174
4.2	Solving a max–min problem as a linear program	176
4.2.1	Problem statement	176
4.2.2	An LP model	177
4.2.3	The $\min\{ \}$ function	178
4.2.4	Finessing the problem	178
4.2.5	The solution to the gambler’s problem	179
4.3	A dynamic transportation problem with inventory	180
4.3.1	Problem statement	180
4.3.2	The single-site purchasing problem	182
4.3.3	Two sites: a transshipment problem	185
4.3.4	The general problem: two sites and five processing plants	188
4.4	Problems	189

5	Output analysis I: small changes	195
5.1	Introduction to sensitivity analysis	195
5.1.1	Methods of analysis	197
5.2	The Lotsa Pasta problem	198
5.3	Graphical representation of linear programs	200
5.3.1	Graphing the feasible region	201
5.3.2	Production plans that satisfy more than one constraint simultaneously	203
5.3.3	Finding an optimal solution	204
5.3.4	Optimality of “corner” solutions	207
5.4	Optimal plans	207
5.5	Small changes in the objective function	208
5.5.1	Changing more than one objective function coefficient	215
5.6	Changing right-hand-side values	216
5.6.1	A proposal you might be able to refuse	216
5.6.2	Shadow prices	219
5.6.3	Small changes in several right-hand-side values	223
5.7	Reduced cost	226
5.7.1	Activity	229
5.7.2	Pricing out the activities	230
5.7.3	Reduced cost as a shadow price	231
5.8	Adding an activity	232
5.9	Multiple optimal solutions	233
5.10	Interpreting Solver output: The BGT Candy Company	234
5.11	Comparing sensitivity reports	240
5.12	Identifying exploitable decisions	244
5.13	Problems	245
5.14	Solutions to some hands-on exercises	270
	Supplement: Duality: the story behind shadow prices	273
5.15	The primal problem	273
5.16	An offer you can’t refuse	274
5.17	The pricing problem	275
5.17.1	Products as bundles of resources	275
5.17.2	Optimal resource prices	277
5.18	Primal–dual pairs	278
5.18.1	The dual of the dual	278
5.19	Interesting properties of primal–dual pairs	281

5.20	Dual variables and shadow prices	283
5.21	Some concluding remarks	284
5.22	A challenging capstone problem	285
5.22.1	The solution	286
5.23	Problems	288
 6 Output analysis II: large changes		291
6.1	The optimal value function for RHS values	291
6.1.1	Revisiting the Lotsa Pasta problem	291
6.1.2	Measuring the benefit of labor hours	292
6.1.3	Generating an optimal value function	294
6.1.4	Properties of the optimal value function	295
6.1.5	Using Solver to generate an optimal value function	297
6.1.6	General properties of optimal value functions	298
6.1.7	Utilizing the optimal value function	298
6.2	Optimal value functions for objective function coefficients	300
6.2.1	The slope of the iso-profit line	301
6.2.2	Generating an optimal value function	301
6.2.3	Properties of the objective function coefficient value functions	305
6.3	Belles and Baubles Trinket Company	306
6.3.1	Determining the trinket demand function	308
6.3.2	Impact of the marginal production cost on the optimal selling price	309
6.4	Problems	310
6.5	Solutions to a hands-on exercise	312
 7 Integer linear programs		313
7.1	Fixed charge problems	313
7.2	Using Solver to solve integer linear programs	315
7.2.1	Farm Implement revisited	316
7.3	Using binary-valued decision variables	318
7.3.1	Mutually exclusive decision variables	318
7.3.2	Contingent decision variables	319

7.3.3	Either/or constraints	320
7.4	A bundle pricing problem	322
7.4.1	Decision variables	323
7.4.2	The objective function	323
7.4.3	Constraints	324
7.5	A production planning problem	328
7.5.1	Cost and other information	328
7.5.2	An integer LP formulation	331
7.6	A river crossing problem	338
7.6.1	An LP formulation	340
7.7	Bond portfolios to satisfy damage judgments	344
7.8	Problems	350
7.9	Solutions to hands-on exercises	354

Part II **Decision making under uncertainty** 357

8 Introduction to probability models 359

8.1	Elements of probability	359
8.1.1	Random experiments	359
8.1.2	Events	360
8.1.3	Probability functions	362
8.2	Conditional probability	365
8.2.1	Law of Total Probability	367
8.2.2	An auditing example	368
8.3	Independent events	371
8.4	Random variables and their distributions	373
8.4.1	The distribution of a random variable	376
8.5	Expectation	377
8.5.1	Properties of expected values	378
8.5.2	Law of the Unconscious Statistician	378
8.6	Variance and standard deviation	379
8.6.1	A property of variance	380
8.7	Joint distributions	381
8.7.1	Conditional expectation	385
8.8	Bayes' Rule	385
8.9	Common discrete probability distributions	389
8.9.1	Bernoulli random variables	389

	8.9.2 Binomial random variables	389
	8.9.3 Geometric random variables	390
	8.9.4 Poisson random variables	391
	8.9.5 Summary of information for some discrete random variables	392
8.10	Continuous random variables	393
	8.10.1 An example: uniform random variables	396
	8.10.2 Exponential random variables	399
	8.10.3 Gamma random variables	400
	8.10.4 Normal random variables	401
	8.10.5 Summary of some common continuous probability distributions	407
8.11	Problems	407
8.12	Solutions to hands-on exercises	414
9	Decision making under uncertainty	420
	9.1 Classes of decision problems	420
	9.2 Introduction to decision theory	421
	9.3 Non-probabilistic methods	422
	9.3.1 Dominance	423
	9.3.2 Decision criteria	423
	9.3.3 Application: managing seasonal goods inventory	426
9.4	Probabilistic methods	428
	9.4.1 The modal outcome criterion	429
	9.4.2 Expected value criterion	430
	9.4.3 Expected regret criterion	430
	9.4.4 The Christmas tree problem revisited	431
9.5	Value of information	432
9.6	Utility and preference	434
	9.6.1 Certainty equivalents	434
	9.6.2 Utility functions	435
	9.6.3 Attitudes towards risk	438
	9.6.4 Exponential utility functions	440
9.7	Problems	443

10	Decision trees	451
10.1	To enter or not to enter?	451
10.2	A new product introduction problem	454
10.3	Depicting the decision process	455
10.3.1	Types of nodes in a decision tree	456
10.4	GM's decision tree	457
10.4.1	Placing data on the tree	459
10.5	Assigning values to the nodes: folding back a decision tree	461
10.5.1	"Pay-as-you-go" node valuation	462
10.5.2	"Settle-up-at-termination" node valuation	463
10.6	Identifying an optimal strategy	466
10.7	Building decision tree models in EXCEL: using TreePlan	466
10.7.1	Building a new decision tree	467
10.7.2	Modifying a decision tree	468
10.7.3	Hints about printing the decision tree	470
10.8	Evaluating new information	472
10.8.1	Quality of information	472
10.8.2	Updating prior beliefs	474
10.8.3	The modified decision problem	477
10.9	Optimal strategies as optimal contingency plans	479
10.10	The value of information	481
10.10.1	The value of perfect information	482
10.10.2	Perfect information and no information	484
10.11	Sensitivity analysis in decision trees	487
10.11.1	Varying the likelihood probabilities	487
10.12	Decision trees with exponential utility	489
10.12.1	Game Magic revisited	490
10.13	An oil exploration problem	497
10.13.1	Availability of information	498
10.13.2	Resolving an apparent paradox	499
10.13.3	Expected value of perfect information	503
10.14	Bidding for the SS <i>Kuniang</i>	503
10.15	Problems	509
10.16	Solutions to some hands-on exercises	524

11	Management of congested service systems	526
11.1	Components of a queueing model	528
11.1.1	Kendall notation	530
11.1.2	A simple deterministic example	530
11.1.3	A general result: Little's Law	532
11.1.4	Another example	534
11.1.5	Steady state versus transient analysis	535
11.2	A basic queueing model	535
11.2.1	Memoryless property of random variables	536
11.2.2	Exponential random variables	536
11.2.3	Poisson arrivals	537
11.2.4	Steady-state analysis	539
11.2.5	Determining the steady-state probabilities	541
11.2.6	Calculating L and W	544
11.2.7	Computing L_q and W_q	545
11.3	Multi-server exponential queues: the M/M/s model	546
11.3.1	The Queue.xls workbook	548
11.3.2	The M/M/s queue with capacity restrictions	549
11.3.3	Erlang's loss formula	550
11.4	An infinite server queue	552
11.5	A finite source exponential queue	553
11.6	M/G/1 queues	554
11.7	Designing queueing systems	557
11.7.1	Controlling the number of servers in an M/M/s queue	558
11.8	Approximate methods for finding the optimal number of servers	559
11.8.1	The deterministic model	560
11.8.2	Applicability	561
11.9	Analysis under the independence assumption	562
11.9.1	A note of caution	565
11.10	The equilibrium model	565
11.10.1	Non-exponential service times	566
11.11	Controlling the rate of service	566
11.12	Who waits longer: one super-server versus multiple slow servers?	570
11.12.1	Average waiting times in M/M/1 queues	570
11.12.2	Average waiting times in M/M/2 queues	571
11.12.3	Comparing $W_q(1)$ and $W_q(2)$	572

11.12.4	Comparing $W(2)$ and $W(1)$	572
11.12.5	The general case	573
11.12.6	Conclusions	574
11.13	Scheduling police patrol cars in New York City	574
11.14	Problems	579
12	Monte Carlo simulation	593
12.1	An overbooking problem: evaluating a restaurant's reservation policy	594
12.1.1	Constructing a simulation model	595
12.1.2	An EXCEL simulation model	595
12.2	Another example	599
12.2.1	Replicating random experiments using the Data Table function	600
12.2.2	Replicating the experiments	600
12.2.3	Summarizing the data	603
12.3	Avoiding automatic recalculation of a worksheet	605
12.4	Using CRYSTAL BALL, an EXCEL add-in for Monte Carlo simulation	606
12.4.1	Solving Bistro 220's problem using CRYSTAL BALL	606
12.4.2	Assumption cells	607
12.4.3	Forecast cells	609
12.4.4	Decision cells	609
12.4.5	Choosing preferences	609
12.4.6	Running OptQuest	610
12.4.7	CB's output	613
12.5	A lump-sum investment problem	613
12.5.1	Some generalizations	616
12.5.2	Summary	621
12.6	Another example: State Driver's License Examination Center	622
12.7	An overview of discrete-event simulation	623
12.7.1	Designing a simulation experiment	623
12.8	Generating values of random variables	625
12.8.1	Generating values of empirical random variables	628
12.8.2	The inverse transform method	632
12.8.3	CB built-in random number generators	635
12.9	Simulating the Driver's License Examination Center	636
12.9.1	Layout of the workbook	636

12.10	Multi-period inventory with random demand	644
	12.10.1 Generating the random demands	645
	12.10.2 Some modeling details	647
	12.10.3 Finding a “good” ordering policy	650
12.11	Kanondell Cycle	652
	12.11.1 Problem statement	652
	12.11.2 Defining Assumptions in CB	656
	12.11.3 Analysis	658
12.12	Problems	659
12.13	Solution to a hands-on-exercise	672
Appendix	An Excel Primer	674
A.1	Cell addressing	674
	A.1.1 A1 cell addressing	674
	A.1.2 R1C1 cell addressing	675
	A.1.3 Managing cell names	675
	A.1.4 Invalid names	677
A.2	Formulas in EXCEL	677
A.3	Array (matrix) formulas in EXCEL	678
	A.3.1 Example: solving systems of linear equations	682
A.4	Logical functions in EXCEL	684
	A.4.1 EXCEL’s AND, OR, and NOT functions	685
	A.4.2 EXCEL’s IF function	686
A.5	Data tables	689
	A.5.1 A (column-type) one-way data table	689
	A.5.2 Two-way data tables	691
A.6	EXCEL’s HLOOKUP and VLOOKUP functions	693
A.7	EXCEL’s Histogram tool	695
A.8	Solutions to some hands-on exercises	700
	<i>Index</i>	703
	<i>CD-ROM</i>	714

Tables

0.1	Applications in management science.	xxxvii
1.1	Cell details in 'Model 1'.	17
1.2	Cell details in 'Usage Analysis'.	20
2.1	Production processing times for the MicroWorks problem.	32
2.2	Revenues and costs for the MicroWorks problem.	33
2.3	Linear program for the MicroWorks problem.	40
2.4	Data for the CTR Company problem.	57
2.5	Linear program for the Cash-for-Trash problem.	60
2.6	Mixing requirements of the two candy lines.	71
2.7	Supply availability and cost of the chocolate types.	71
2.8	BGT product mix problem.	73
2.9	The BGT product mix problem in LP Standard Form.	74
2.10	Optimal recipe for the BGT candies.	76
2.11	Data for Problem 2.1.	78
2.12	Data for Problem 2.2.	78
2.13	Data for Problem 2.3.	79
2.14	Data for Problem 2.7.	81
2.15	Data for Problem 2.8.	82
2.16	Data for Problem 2.12.	83
2.17	Revenue and material costs. (Problem 2.12).	84
2.18	Data for Problem 2.13.	85
2.19	Data for Problem 2.14.	85
2.20	Data for Problem 2.15.	86
2.21	Data for Problem 2.16.	86
2.22	Data for Problem 2.18.	88
2.23	Data for Problem 2.19.	88
2.24	Data for Problem 2.20.	89
2.25	Data for Problem 2.21.	90
2.26	Data for Problem 2.22.	90
2.27	Data for Problem 2.23.	91

3.1	Investment opportunities.	98
3.2	Linear program for Western Trust's portfolio selection problem.	99
3.3	Data for the Wisconsin Paper Company problem.	101
3.4	Cost data for the Rent-a-Hauler Company problem.	103
3.5	Model for the Rent-a-Hauler Company problem.	105
3.6	Physical characteristics of the ship.	107
3.7	Potential cargo.	107
3.8	Linear program for Captain Wise's problem.	108
3.9	Staffing requirements for the University Computer Center.	111
3.10	Linear program for a staff scheduling problem.	113
3.11	Expected annual net cash flows.	115
3.12	Terminal net worth linear program for the Global Investments Company.	118
3.13	Modified cash inflows and outflows.	123
3.14	Optimal solutions to three models.	123
3.15	Needs and costs.	124
3.16	Data for the Precision Products problem.	128
3.17	Unit prices for each component.	132
3.18	Indebtedness array for the disentangling problem.	138
3.19	Linear program for the disentanglement problem.	138
3.20	Amounts paid and received.	140
3.21	Data for Problem 3.1.	141
3.22	Data for Problem 3.5.	143
3.23	Data for Problem 3.6.	144
3.24	Data for Problem 3.7.	144
3.25	Data for Problem 3.9.	146
3.26	Data for Problem 3.10.	146
3.27	Data for Problem 3.12.	147
3.28	Data for Problem 3.13.	148
3.29	Data for Problem 3.14.	148
3.30	Data for Problem 3.15.	149
3.31	Data for Problem 3.16.	150
3.32	Data for Problem 3.18.	151
3.33	Data for Problem 3.20—crude oil.	153
3.34	Data for Problem 3.20—motor oil.	153
3.35	Data for Problem 3.21.	154
3.36	Data for Problem 3.22.	154
3.37	Number of passengers (in thousands).	154
3.38	Aircraft operating costs.	155
3.39	Data for Problem 3.24.	156
3.40	Data for Problem 3.27.	158

3.41	Annual cash flows.	159
3.42	Data for Problem 3.28.	160
3.43	Projected rates of sales.	160
3.44	Data for Problem 3.29.	161
3.45	Data for the Pure Temper problem.	162
3.46	Time required for each operation.	163
3.47	Data for Problem 3.32.	164
3.48	Data for Problem 3.33.	165
3.49	Data for Problem 3.34.	166
3.50	Data for Problem 3.35.	167
3.51	Solid State's balance sheet.	167
4.1	Data for High Margins' products.	171
4.2	Linear program for High Margins, Inc.	173
4.3	Production planning LP for the Precision Products problem with backlogging.	176
4.4	Payoff rates by choice and outcome.	178
4.5	An LP that maximizes a minimum payoff.	180
4.6	Linear program to determine Site 1's optimal purchasing plan.	183
4.7	Decision variables and parameters in the BOM problem.	184
4.8	Linear program to determine Sites 1 and 2's optimal purchasing and shipping plans.	185
4.9	Formula in the 'Sites 1 and 2' workbook.	186
4.10	Linear program to determine Site 1 and Site 2's optimal purchasing and shipping plans with five processing plants.	189
4.11	Formulas in the Complete worksheet of BOM.xls.	190
4.12	Data for Problem 4.1.	192
4.13	Data for Problem 4.2.	194
5.1	Linear program for the Lotsa Pasta problem.	199
5.2	Sample sensitivity analysis questions in the Lotsa Pasta problem.	200
5.3	Sign of the shadow price.	222
5.4	Decreasing the availability.	238
5.5	Increasing the objective function.	239
5.6	Data for Problem 5.7.	252
5.7	Data for Problem 5.8.	255
5.8	Linear program for the Weedwacker problem.	255
5.9	Data for Problem 5.9.	258
5.10	Model for the PowerTrain problem.	258

5.11	Data for Problem 5.18.	268
5.12	Relationships between primal and dual programs.	278
5.13	Linear program for Problem 5.20.	288
5.14	Linear program for Problem 5.21.	289
6.1	The Lotsa Pasta linear program.	292
7.1	Data for the Mercury Machine Shop problem.	314
7.2	Integer LP for the Mercury Machine Shop problem.	314
7.3	Data for the Acme Manufacturing problem.	320
7.4	Data for Micro Wholesale's bundle pricing problem.	322
7.5	Linear program for the MW bundle pricing problem.	326
7.6	Demand for pale ale in barrels.	328
7.7	Costs and capacities by workforce level.	331
7.8	Changeover cost verification.	335
7.9	The dependence between Z_t and S_{t-1} and S_t .	335
7.10	Objective function of the RTA integer LP.	336
7.11	Constraints in the RTA production planning problem.	337
7.12	RTA's optimal production plan.	340
7.13	Name codes and crossing times.	341
7.14	An integer linear program for the River Crossing problem.	345
7.15	An optimal solution to the River Crossing problem.	347
7.16	An integer linear program for the bond portfolio problem.	349
7.17	Data for Problem 7.1.	350
7.18	Data for Problem 7.2.	351
7.19	Data for Problem 7.3.	353
7.20	Data for Problem 7.6.	355
7.21	The new optimal production plan for RTA.	356
8.1	Number of candies in three dishes.	361
8.2	Definitions for Example 8.2.	363
8.3	A joint probability table.	371
8.4	Joint probabilities of bags sold and competitor's price.	372
8.5	Partially filled table of joint probabilities.	373
8.6	Completed table of joint probabilities.	374
8.7	Total cost for two records.	374
8.8	The distribution of C	376
8.9	Distribution of weekly sales X .	381
8.10	Joint distribution of C and S .	382
8.11	Distribution of X .	383
8.12	Cumulative distribution of X .	383

8.13	Common discrete probability distributions.	394
8.14	Common continuous probability distributions.	406
8.15	Distribution of Y .	415
9.1	Total profit $\Pi(x, d)$.	428
9.2	Computing the optimal decision under the maximin and maximax criteria.	428
9.3	$L(x, d)$, regret (opportunity loss) for the Christmas tree problem.	429
9.4	Distribution of D , the demand for Christmas trees.	432
9.5	Data for a problem with uncertainty.	436
9.6	Data for problem with uncertainty using utility values.	438
9.7	Data for Problem 9.1.	443
9.8	Data for Problem 9.6.	446
9.9	Data for Problem 9.7.	447
10.1	Payoff table for the Book Browser problem.	452
10.2	Computing the value of a node in the “pay-as-you-go” setting.	463
10.3	Computing the value of a node in the “settle-up-at-termination” setting.	465
10.4	Joint probability table for Game Magic.	475
10.5	Acquisition and restoration cost (in \$ millions).	506
10.6	Maximum expected net present values associated with each bid value.	508
10.7	Data for Problem 10.2.	510
10.8	Data for Problem 10.5.	513
10.9	Data for Problem 10.6.	514
10.10	Joint probabilities of input and output casting quality.	519
10.11	Data for Problem 10.14.	520
10.12	Data for Problem 10.16.	523
10.13	Applications under the proposed system.	523
11.1	Managerial problems characterized by congestion.	527
11.2	The total cost of providing service as a function of the number of ATMs.	559
11.3	Parameters and variables used to compute the profit per unit time.	560
11.4	The optimal number of servers with Poisson arrivals and an infinite number of servers.	563
11.5	The optimal number of servers in an M/M/s queue.	566

11.6	Cost of providing various rates of service.	568
11.7	Model for the patrol car scheduling problem.	578
11.8	Some formulas in Figure 11.20.	579
11.9	Data for Problem 11.11.	589
12.1	Components of a simulation model.	624
12.2	Distribution of sales, S .	629
12.3	EXCEL statistical functions for distribution and inverse distribution functions of several random variables.	633
12.4	Built-in CB probability functions.	635
12.5	Data for Problem 12.6.	665
12.6	Data for Problem 12.8.	666
12.7	Data for Problem 12.9.	667
12.8	Distribution of purchases by group and mean and standard deviation of purchase amounts within each group.	668
12.9	Distribution of the number of customers who enter the shop with and without the new advertising.	670
12.10	Parameters of the normal distribution of individual sales.	671
A.1	Logical operators in EXCEL.	685

Figures

1.1	Building and implementing decision models.	9
1.2	An influence diagram for the lease/buy problem.	12
1.3	The LeaseBuy.xls workbook.	14–15
1.4	An influence diagram for the modified lease/buy problem.	19
1.5	The Goal Seek function.	22
1.6	Leasing and purchasing costs as a function of the annual usage rate.	23
1.7	Years worksheet added to LeaseBuy.	25
1.8	Years worksheet after using Goal Seek.	25
1.9	Leasing and purchasing costs as a function of the length of the planning horizon.	26
2.1	An influence diagram for a generic optimization problem.	31
2.2	Spreadsheet model for the MicroWorks problem.	42
2.3	Solver menus.	47
2.4	Solver Options dialog box.	48
2.5	Entering constraints into Solver's Add Constraint box.	49
2.6	Completed Solver dialog box.	50
2.7	Solver Results box.	51
2.8	Answer Report for the MicroWorks problem.	52
2.9	The MicroWorks spreadsheet model evaluated at the optimal solution.	52
2.10	Adding the restriction that the decision variables be integer-valued.	55
2.11	One ton of trash.	60
2.12	The CTR spreadsheet model.	61
2.13	Entering constraints into Solver's Add Constraint box.	63
2.14	Completed Solver dialog box.	64
2.15	Solver Answer Report.	65
2.16	CTR model worksheet after running Solver.	65
2.17	Profit maximizing variation of the CTR problem.	66
2.18	The StdFormTemplate.xls workbook.	67

2.19	Spreadsheet model for the BGT problem.	75
2.20	Solver model for the BGT problem.	75
3.1	A geometrical representation of decision problem types.	94
3.2	Spreadsheet model for Western Trust's portfolio selection problem.	100
3.3	Solving a cutting-stock problem.	102
3.4	Directed graph for the Rent-a-Hauler Company problem.	103
3.5	Spreadsheet model of the Rent-a-Hauler Company problem.	105
3.6	Spreadsheet model for Captain Wise's problem evaluated at the optimal solution.	110
3.7	Spreadsheet model for the staff scheduling problem.	114
3.8	Terminal net worth model.	118
3.9	Discounted cash flow model.	121
3.10	Auditor model in Standard Form.	126
3.11	Auditor model in alternate form.	126
3.12	The Precision Products spreadsheet model.	131
3.13	Spreadsheet model for Farm Implement when Supplier 1 is used.	134
3.14	Spreadsheet model for Farm Implement when Supplier 1 is not used.	136
3.15	Optimal solution to the disentanglement problem.	139
4.1	Total profit function for Product 3.	171
4.2	Spreadsheet model for the High Margins product mix problem.	173
4.3	Precision Product's spreadsheet model with backlogging.	177
4.4	Graph of the function $f(x) = \min\{x + 1, 2 - x\}$	179
4.5	Gambler's spreadsheet model.	180
4.6	The Data worksheet in BOM.xls.	182
4.7	Worksheet 'Site 1 Only'.	184
4.8	Worksheet 'Sites 1 and 2'.	188
4.9	Worksheet Complete.	192
5.1	Spreadsheet model for the Lotsa Pasta Company problem.	199
5.2	Answer Report for the Lotsa Pasta Company problem.	199
5.3	Production plans that use no more than 90 hours of labor.	202
5.4	The feasible production plans.	204
5.5	Iso-profit production plans.	205
5.6	Production plans that generate \$1,750 in total profits.	206
5.7	Increasing the profit margin of macaroni.	209
5.8	Multiple optimal solutions when $m_w = 700$.	210
5.9	Optimal production plan when $m_w = 250$.	211
5.10	Multiple optimal solutions when $m_w = 200$.	212

5.11	The Sensitivity Report for the Lotsa Pasta problem.	213
5.12	The Lotsa Pasta problem in AnimaLP.	214
5.13	The expanded feasible region with $b_1 = 100$.	218
5.14	Example wherein a binding constraint has a zero shadow price.	223
5.15	Optimal solution when $m_z = 0$.	227
5.16	Optimal solution when $m_z = 0$ and $Z \geq 1$.	227
5.17	Sensitivity Report when $m_z = 0$.	228
5.18	Optimal solution when $m_z = 150$.	229
5.19	Lotsa Pasta model when $m_z = 0$.	230
5.20	Signal for multiple optimal solutions in the Lotsa Pasta model.	233
5.21	Answer Report for the BGT Candy Company problem.	234
5.22	Sensitivity Report for the BGT Candy Company problem.	235
5.23	Alternate form model for the Precision Products Company.	240
5.24	Sensitivity Report for alternate form problem.	241
5.25	Standard Form model for the Precision Products Company.	242
5.26	Sensitivity Report for the Standard Form problem.	242
5.27	Right-hand-side analysis.	243
5.28	Sensitivity Report for the CTR problem.	244
5.29	Spreadsheet model for the Putter Partners problem.	252
5.30	Answer Report for the Putter Partners problem.	253
5.31	Sensitivity Report for the Putter Partners problem.	253
5.32	The spreadsheet model for the Weedwacker problem.	256
5.33	Answer Report for the Weedwacker problem.	256
5.34	Sensitivity Report for the Weedwacker problem.	257
5.35	Spreadsheet model for the PowerTrain problem.	259
5.36	Answer Report for the PowerTrain problem.	259
5.37	Sensitivity Report for the PowerTrain problem.	260
5.38	The spreadsheet model for the Hippopotamus shipping problem.	261
5.39	Sensitivity Report for the Hippopotamus shipping problem.	262
5.40	Feasible region for the product mix problem.	274
5.41	An example of a primal–dual relationship.	279
5.42	The relation between objective function values in primal–dual pairs.	282
5.43	The relation between optimal solutions to primal–dual pairs of linear programs.	284
5.44	Feasible region for the dual problem.	287
6.1	Varying labor hours in the Lotsa Pasta problem.	293
6.2	Optimal profit as a function of the number of labor hours available.	296

6.3	Data from three Sensitivity Reports.	298
6.4	General shapes of optimal value functions associated with RHS values.	299
6.5	Optimal net profit as a function of the number of labor hours available.	300
6.6	Optimal solution when $p_w = 0$.	301
6.7	Optimal solution when $p_w = 200$.	302
6.8	Optimal solution when $p_w = 700$.	304
6.9	Optimal solution when $p_w \rightarrow \infty$.	304
6.10	Graph of $v_w(p_w)$.	305
6.11	Optimal solution to Captain Wise's problem when $P = \$2,500$.	307
6.12	Sensitivity Report for the variable T in the objective function.	308
6.13	Computing B&B's profit maximizing price.	309
7.1	The spreadsheet model for the Mercury Machine Shop problem.	316
7.2	Specifying binary variables in Solver.	316
7.3	Integer LP model for Farm Implement evaluated at the optimal solution.	317
7.4	Decision model for the Acme Manufacturing problem.	321
7.5	The left half of the MW bundle pricing spreadsheet model.	329
7.6	The right half of the MW bundle pricing spreadsheet model.	330
7.7	The left half of the RTA spreadsheet model.	338
7.8	The right half of the RTA spreadsheet model.	339
7.9	The five required trips.	341
7.10	The spreadsheet model for the River Crossing problem.	344
7.11	A bond portfolio selection model.	348
8.1	Probability tree diagram for Example 8.2.	364
8.2	Probability tree diagram for Example 8.3.	365
8.3	Joint distribution of values from two selections with replacement.	384
8.4	Computing probabilities for a geometric random variable.	391
8.5	The cdf and pdf of a uniform $(0, 1)$ random variable.	397
8.6	Computing the mean and standard deviation of X .	414
8.7	Joint probability table for selection without replacement.	415
8.8	Workbook for hands-on exercise 8.1.	416
9.1	$U(x)$, utility of payoff x .	437
9.2	A utility function $U(x)$ of a risk averse DM.	439
9.3	Exponential utility functions.	441

10.1	Decision tree for the Book Browser problem.	453
10.2	The Data worksheet for the GM decision tree.	455
10.3	Terminal node with payoff of +50.	456
10.4	Event node with three possible outcomes.	457
10.5	Decision node with two alternatives.	457
10.6	Basic structure of the decision tree for the GM problem.	458
10.7	GM decision tree with data.	460
10.8	GM decision tree with “pay-as-you-go” node valuation.	464
10.9	GM decision tree with “settle-up-at-termination” node valuation.	465
10.10	TreePlan’s initial decision tree.	467
10.11	Modifying a decision tree in TreePlan.	468
10.12	TreePlan’s modified decision tree.	469
10.13	A partially completed decision tree.	470
10.14	TreePlan’s Copy subtree option.	471
10.15	TreePlan’s Paste subtree option.	471
10.16	The decision tree immediately after the Paste subtree command.	472
10.17	Modified Data worksheet.	476
10.18	TreePlan’s modified decision tree.	478
10.19	Summary of the solution to the GM problem in the Results worksheet.	480
10.20	Computing EPPI.	485
10.21	Varying the likelihood probabilities.	486
10.22	Modifying TreePlan’s node evaluation option.	491
10.23	Specifying expected utility maximization in TreePlan.	492
10.24	Game Magic decision tree with expected utility criterion.	493
10.25	GM’s utility function when $A = B = 10$ and $RT = 50$.	494
10.26	GM’s decision tree with expected utility payoffs.	495
10.27	Optimal first actions for various levels of risk aversion.	496
10.28	The Essex Oil Company decision problem.	498
10.29	The modified Essex Oil Company decision problem.	500
10.30	The revised Essex Oil Company decision problem.	502
10.31	Beginning of NEES’s decision tree.	506
10.32	Continuation of NEES’s decision tree for a \$6 million bid.	507
10.33	Partial decision tree for Problem 10.4.	512
11.1	A typical queueing system.	526
11.2	Number of customers in a deterministic queueing system.	530
11.3	Number of customers in another queueing system.	534
11.4	Transition diagram for an M/M/1 queue.	541
11.5	Worksheet M-M-s in the workbook Queue.xls when $s = 1$.	547

11.6	Worksheet M-M-s in the workbook Queue.xls when $s = 2$.	548
11.7	Worksheet M-M-s-K in the workbook Queue.xls.	549
11.8	Analyzing an M/G/s/s queueing model.	551
11.9	Analyzing an M/G/ ∞ queueing model.	552
11.10	Analyzing an M/M/s queueing model with a finite source.	554
11.11	Modeling a drive-through facility as an M/M/1 queueing model.	555
11.12	Modeling a drive-through facility with automation as an M/G/1 queueing model.	556
11.13	The modified M/G/1 queueing model.	557
11.14	Service and waiting costs as a function of the service rate.	558
11.15	A spreadsheet model for the infinite server approximation with Poisson arrivals.	564
11.16	The Calc sheet in Copier Cost.	568
11.17	Number of patrol cars demanded by hour.	574
11.18	Calculating the number of patrol cars required by hour.	576
11.19	Patrol car demand and requirements by hour.	577
11.20	Determining an optimal patrol car schedule.	580
11.21	The assignment of patrol cars by hour.	580
12.1	Bistro 220 spreadsheet model.	596
12.2	Data table to determine the optimal number of reservations to accept.	598
12.3	Setting up a data table for replicating a simulation experiment.	601
12.4	Completed data table showing 1,000 replications of two experiments.	602
12.5	Output of the Descriptive Statistics function.	603
12.6	Histograms of values generated in Experiments 1 and 2.	604
12.7	Defining an assumption cell in CB.	608
12.8	Defining another assumption cell in CB.	608
12.9	Gallery of some of the distributions available in CB.	609
12.10	Defining a forecast cell in CB.	610
12.11	Defining a decision cell in CB.	610
12.12	Setting preferences in CB.	611
12.13	Selecting a decision variable in OptQuest.	612
12.14	The Forecast Selection window in OptQuest.	612
12.15	Selecting options in OptQuest.	612
12.16	The Status and Solutions window in OptQuest.	613
12.17	The distribution of daily net contribution.	614
12.18	Forecast statistics generated by CB.	614

12.19	The principal saved/owed when a loan is made at time T .	615
12.20	Determining T with daily compounding.	617
12.21	Determining T with random interest rates.	619
12.22	The distribution of total net annual interest when $T = 214$.	621
12.23	The State Driver's License Examination Center.	623
12.24	The distribution function of a triangular (a, b, c) random variable.	627
12.25	Transforming a symmetric triangular $(0,2)$ pdf into a symmetric triangular (a, b) pdf.	628
12.26	The cumulative distribution of S .	629
12.27	Evaluating the cumulative distribution of S .	630
12.28	Using =VLOOKUP	631
12.29	Illustration of the inverse transform method for generating values of random variables.	632
12.30	Generating values of triangular $(1, 5, 2)$ random variables.	634
12.31	Parameters sheet of the License Examination Center simulation model.	637
12.32	Model sheet of the License Examination Center simulation model.	637
12.33	Repetitions sheet of the License Examination Center simulation model.	638
12.34	Distribution of the average time spent in the Center over all customers.	642
12.35	Statistics for the average time spent in the Center over all customers.	643
12.36	Mean and standard deviation of daily demand (Demand worksheet).	645
12.37	Parameter values and costs (Parameter worksheet).	646
12.38	Simulating an (s, S) inventory policy (Model worksheet).	646
12.39	Input to OptQuest (Parameter worksheet).	650
12.40	Specifying constraints in OptQuest.	651
12.41	OptQuest's optimal solution.	652
12.42	OptQuest's Sensitivity Report.	652
12.43	CB's report when $S = 282$ and $s = 181$.	653
12.44	Data and model for the road bike proposal (Road worksheet).	655
12.45	Data and model for the mountain bike proposal (Mountain worksheet).	655
12.46	Entering a custom sales distribution.	657
12.47	Distribution of ROI values.	658
12.48	The difference in frequencies between mountain and road bike ROI distributions.	659

A.1	Main worksheet in EqSolver.xls.	676
A.2	Computation worksheet in EqSolver.xls.	678
A.3	Data for hands-on exercise A.4.	682
A.4	The Main worksheet in EqSolver.xls.	683
A.5	Resulting worksheet using EqSolver.xls.	684
A.6	Computing total cost based on conditions.	688
A.7	A simple profit model.	690
A.8	Setting up a (column-type) one-way data table.	690
A.9	Specifying the Column Input Cell for a (column-type) one-way data table.	691
A.10	A completed (column-type) one-way data table.	692
A.11	A completed multi-column one-way data table.	692
A.12	Setting up a two-way data table.	693
A.13	Generating a two-way data table.	694
A.14	A completed two-way data table.	694
A.15	Using the VLOOKUP function.	695
A.16	Selecting the Histogram tool in the Data Analysis menu.	697
A.17	The main Histogram tool menu.	697
A.18	Histogram generated with EXCEL's bin values.	698
A.19	Using EXCEL's Fill-Series function.	699
A.20	Specifying a range of bin values in the Histogram tool.	699
A.21	Histogram generated with user-specified bin values.	700
A.22	Solution to hands-on exercise A.4.	701

The science of managerial decision making

“The right merchant is one who has the just average of faculties we call common sense; a man of a strong affinity for facts, who makes up his decision on what he has seen. He is thoroughly persuaded of the truths of arithmetic. There is always a reason, in the man, for his good or bad fortune . . . in making money. Men talk as if there were some magic about this. . . . He knows that all goes on the old road, pound for pound, cent for cent—for every effect a perfect cause—and that good luck is another name for tenacity of purpose.”

Ralph Waldo Emerson
The Conduct of Life, “Wealth” (1860)

1.1 Introduction

Management is decision making. All right, this might be a bit of an overstatement, since management more broadly construed entails many important functions, including motivation, inspiration, and leadership, that do not explicitly conjure up notions of decision making. But, since this a book about decision making, our focus is on this important managerial function.

Some decisions are easy to make and others are not. Why? While there might be many reasons, here are some that are particularly relevant to the issues explored in this book:

- *Information*

In many problem settings, all of the relevant information that we need to make good decisions is readily available and we are able to effectively use this information in the decision-making process. In other settings, information may be available, but we cannot effectively use it because of limitations in our own mental processing or because we do not have the appropriate technologies, such as computers, to assist us in marshaling this information into usable forms.

- *Uncertainty*

Many decision problems are complicated by uncertainty. For example, suppose we would like to introduce a new product to the market and

want to plan the size of the manufacturing facility that should be built to produce the product. Unfortunately, we don't know what the demand for the new product will be, and we may not know exactly what the startup cost of developing the product will be. When uncertainties such as these are present, we can use two different ways to reach a good decision. One is to *simulate*, on the computer, different combinations of likely demands and startup costs, to give us a better idea of the likely values of the resulting profit. The other method is to use mathematical and statistical methods to calculate the expected value of profit (and, to some extent, also calculate the risk of loss) without having to resort to computer simulation. The advantage of this approach compared to simulation is that it generally gives more reliable conclusions, if the underlying mathematical assumptions are not too unrealistic.

- *Scarce resources*

What may be surprising is that there are many decision problems that are highly complex *even though there is no uncertainty and we have all of the relevant information*. When productive resources are scarce and we are faced with competing alternatives for the use of these resources, we face the complex problem of evaluating trade-offs. "If we choose to do this, we can't do that." We can't do everything, so how do we most effectively utilize our scarce resources?

- *Psychological factors*

Many times decision making is made difficult by significant psychological factors such as fear, power, and anxiety. The quality of our decisions could be influenced by the order in which we acquire information, by our attitude towards taking risks, or by the quality of our reasoning ability. While the psychological factors can be extremely important in decision making, we do not explicitly consider these factors in this book. Instead, we simplify the analysis by focusing on the decisions made by a "rational economic" person. Note that "simply" does not mean "simple". We will see that even in the simpler, rational world, major complexities remain.

1.1.1 Part I: decision making using deterministic models

Part I of this book concerns managerial decision making in the absence of uncertainty. We will *assume* that we know all there is to know about a particular problem. Much of the focus in this section is on the evaluation of *economic trade-offs* resulting from the presence of scarce resources.

The focus in Part I is on the development and analysis of *linear programs*. Examples of some of the problems that are studied in this part of this book include the following:

- *Product mix problems.* Determine how many units of each of several products to produce, given resource limitations. In Chapter 2, we analyze a problem confronting the MicroWorks Company. MicroWorks produce printed circuit boards for personal computers. They are trying to determine how many of each of three different types of boards should be produced next month, given limited availability of certain types of equipment. In Chapter 3, we analyze a problem that concerns the management of cash flows over time. Global Investment Company has a number of potential projects in which they can invest. The investment in a particular project affects the amount of cash that is available over the next three years. We will formulate a decision model that specifies the investment portfolio that maximizes the amount of cash Global will have at the end of three years.
- *Blending problems.* What recipe should be used to make a product when some of the ingredients are scarce? In Chapter 2, we study a problem confronting Cash-for-Trash, a recycling company, who must determine the “recipe” for the trash they process. (The recipe specifies how much trash from certain locations are processed at their facility.) In Chapter 3, we determine the “recipe” for an investment portfolio that specifies how much of each investment opportunity to include in a portfolio so as to maximize its annual net return.
- *Cutting stock problems.* If items are being cut out of common stock, what pattern generates the most usable number of items for a given amount of stock? In Chapter 3, we see that the Wisconsin Paper Company produces finished rolls of various widths of bond paper by cutting wider rolls using several possible cutting patterns. We formulate a decision model that specifies the cost minimizing the number of wide rolls to cut with each of the possible patterns.
- *Capital budgeting problems.* Determine the amount to invest in certain capital projects, given restrictions on cash flows. In Chapter 3, we analyze a problem facing the Global Investment Company. There are a number of projects in which they can invest. Each project affects the amount of cash that is available over the next three years. We will formulate a decision model that determines the investment portfolio that maximizes the amount of cash Global has at the end of three years. We then compare this portfolio to one that maximizes the sum of discounted cash flows over the three-year period.
- *Staff scheduling problems.* Determine the number of employees to have on hand, given limitations on the time that individual employees are available to work. In Chapter 3, the University Computer Center must set up a two-day, 24-hours per day staffing schedule that meets anticipated demand at the lowest possible cost.

- *Network flow problems.* Determine how to efficiently move resources that are at one “location” to other “locations” that demand these resources. The Rent-a-Hauler Company, in Chapter 3, has rental trucks in several cities that could be better utilized in other cities. We formulate a model that specifies how these trucks should be reallocated in order to minimize the total cost of reallocation.
- *Production and inventory management problems.* The issue is to determine if today’s demand for our product should be filled from items held in inventory or by today’s production, given limitations on productive capacity. In Chapter 3, we address the production planning problem confronting the Precision Products’ Company. They must determine how many units should be produced in each of four months so that demand in each month is met. Productive capacity in some months is not sufficient to produce enough in that month to meet that month’s demand—some of the units must be produced in earlier months and held in inventory. In addition, the cost of production varies by month, so it may be cheaper to produce products in an earlier month and to hold them in inventory until they are sold in a later month. We formulate and solve a model that determines when the items should be produced so that total production plus inventory carrying costs are minimized.
- *Bundle pricing problem.* Determine which products should be sold together as a bundle, given consumer preferences for each product in the bundle. Once the bundles have been designed, determine the price of each bundle. In Chapter 7, we study the problem facing Micro Wholesale (MW). MW can sell seven different “bundles” of personal computer components, such as CPUs, hard drives, and CD-ROM drives. The problem is to determine which of the bundles to offer for sale and what the price for each bundle should be. These decisions are based upon market demand information and the cost of producing each bundle.

The material in Part I has the following logical structure. Chapters 2–4 deal with

- *formulation* of decision models;
- the *construction* of spreadsheet models in EXCEL that are based on these formulations;
- the *computation* in EXCEL of optimal solutions that prescribe “the best” course of action that should be taken.

In Chapters 5 and 6, we study *properties* of the optimal solutions to our decision problems:

- *Why* does the solution have the characteristics that it does? Of all of the possible answers, why did EXCEL choose the one it did?

- *What* happens to the optimal solution if some of the underlying data of the problem change? Suppose the profit margin for one of the products we produce increases by 20%? What happens to the optimal production plan we just computed in EXCEL?
- *What* are the important interactions in the model that deserve close managerial scrutiny? Which resources are truly *scarce*? What is their true *economic* value?

The answers to these and related questions constitute *sensitivity analysis* (or *post-optimality analysis*).

Chapter 7 examines problems which require that decisions be expressed as integer numbers. The bundle pricing problem discussed earlier is an example of a problem wherein inclusion of the restriction that some decisions be represented by integer numbers makes it possible to construct a decision model.

1.1.2 Part II: decision making under uncertainty

In Part II of the book, we add some spice to the pot by explicitly allowing some elements of the problem to be uncertain. *Probability models* are used to analyze problems characterized by uncertainty.

Chapter 8 reviews some important elements of probability and discusses several fundamental probability models.

Chapter 9 is an introduction to *decision analysis*, the study of decision making in an uncertain environment. One of the problems we study concerns the management of seasonal goods inventories. A Christmas tree retailer must decide how many trees to order from a nursery before the Christmas season. The retailer incurs a cost of disposing of any trees that are unsold at the end of the season. The retailer does not know what the demand for trees will be and cannot place orders for additional trees once the season begins. How many trees should be ordered before the beginning of the season so that the retailer's total average profit is maximized?

Problems that involve both uncertainty and decision making over several time periods are analyzed through the use of *decision trees* in Chapter 10. One of the problems we study concerns bidding for the salvage rights to a sunken ship. New England Power would like to refurbish a sunken vessel to increase its coal-hauling capacity on the Eastern seaboard. Their decision whether or not to place a bid for the salvage rights to the vessel and the amount of the bid they should make if they decide to participate in the auction is complicated by two major sources of uncertainty. First, of course, they don't know what the bids of the other competitors will be. Second, they do not know the salvage value that the Coast Guard will assign to the vessel. The Coast Guard's salvage valuation plays a critical role in New England Power's cost calcula-

tions. Should New England Power bid for the salvage rights? If so, how much should they bid?

In Chapter 11, we study the management of congested *service systems* by developing and analyzing *queueing models*. We will see how the New York City Police Department uses tools developed in this and other chapters to establish schedules for patrol cars that meet highly variable service call requirements.

Finally, in Chapter 12 we analyze the performance of complex organizations using *Monte Carlo simulation*. Simulation models are constructed in EXCEL that mimic the behavior of complex business processes. Analysis of the simulation output gives insight into the impact that changes in the design might have on the performance of the system. One of the systems we study is the State License Examination Center, where driving tests are administered and licenses are issued to those who pass the test. The Secretary of State has issued guidelines that specify the maximum amount of time it should take to issue a driver's license. We develop a simulation model of the Center to determine if these guidelines are currently being met.

All of the applications we study entail the development and analysis of a model. In the next section, models and model building are discussed in fairly general terms. This chapter then concludes with the detailed analysis of a lease/buy problem that illustrates many of the ideas that permeate the remainder of the book.

1.2 Models

The focus of this book is on the development and analysis of models. There are many types of models that may be used in decision making. Ackoff and Sasieni¹ describe three broad categories or types of models that are used in decision making:

- *Iconic models* are a representation of an object that preserves salient features of that object but usually involves a change of scale. Examples of iconic models include model airplanes, ships, and automobiles, photographs, and doll houses.
- *Analog models* use one set of characteristics to represent another set of characteristics. Analog computers, for example, represent physical and chemical interactions in terms of electrical circuits. Graphs that reflect the relationship among two or more variables use the shape of the curve as an analog of the “true” relationship.
- *Symbolic models* use letters (Roman, Greek, and others), numbers, and other symbols to represent relationships that are typically expressed in

terms of variables. These models tend to be mathematical expressions, which are easily manipulated.

While all these model types might be used to solve managerial problems, we will deal primarily with symbolic models. In particular, virtually all of the models we study in this book are developed in terms of mathematical relationships among variables.

Model building is more art than science. By its very definition, model building is a simplification of reality. When addressing a complex problem, there are typically no signposts that indicate which are the important relationships that must be maintained and which are the ones that can be either ignored or highly simplified. Choosing what to include and how to include it and what to leave out requires experience, ingenuity, and other intangible factors that cannot be easily taught. We will develop model-building skills through practice. We will generate a great deal of experience by doing many problems, some of them in the chapters and many of them as end-of-chapter exercises.

What makes a *good model*? John D.C. Little² identifies six major attributes of a managerial decision-making process which he defines as a *decision calculus*. In order for a modeling-based procedure to be an effective and useful managerial weapon, it should possess the following characteristics:

- *Simplicity*

Include only the important relationships in the model. Simplicity fosters understanding and efforts to include extensive details should be resisted.

- *Robustness*

It should be difficult to make the model generate bad answers. This can be accomplished by restricting possible answers to be within some predetermined range.

- *Ease of control*

It should be easy to generate virtually any output by choosing appropriate inputs. The idea is not that it should be easy to generate any answer that is desired, but that the manager using the model must be confident it is working in a sensible manner.

- *Adaptiveness*

It should be easy to update both the structure and parameters of the model to include new information as it becomes available.

- *Completeness on important issues*

The structure of the model must be capable of effectively handling a variety of problem settings. Also, the model should be capable of using subjective judgments of those directly involved with the use of the model.

- *Ease of communication*

In the parlance of today's computer languages, the computer-based model should be "user-friendly".

1.2.1 Stages of model development

There are typically five stages in the development of a model-based decision-making project:

1. Problem formulation

The problem itself must be identified. Potential courses of action must be selected. It must be determined who has the ability and authority to make decisions. *Objectives* must be identified; that is, there must be some procedure in place that measures the impact of the actions that are taken on the performance of the system.

2. Model construction

The actual model is specified. In much of our analysis, this specification will consist of the construction of mathematical relationships. Sometimes, however, the model may simply be a description of tasks that must be done to complete some activity and a description of rules regarding the sequencing of those tasks.

3. Determining a solution

In this book, we will use the computer to determine a solution to the problem articulated by our model. For the most part, we will use EXCEL and its add-in tools to find an *optimal* solution; that is, a solution that is in some sense “better” (at least no worse) than any other candidate solution. For this reason, the model we develop and analyze is called an *optimization model*.

4. Evaluating and testing the solution

We will spend a great deal of time evaluating the solution generated by the computer. As managers, we are interested in *why* a particular plan of action is better than other possible plans. We seek to identify important economic interrelationships in the problem setting so that we know where to focus our scarce managerial resources. As managers, our objective is not only to “solve” the problem but to gain insights into the problem structure.

5. Implementing the solution

The output of the model is now translated back into the real problem setting. While this is an important phase of the decision-making project, many of the issues in this step of the modeling process are unique to the particular problem setting. Given the space limitations of this text, we will not discuss implementation issues in any great detail.

Figure 1.1 depicts the relationship among the various elements of the model. The left half of the figure relates to the “real world” in which the problem resides (inputs to the analyst) and where the implementation of the solution takes place (the output of the analyst’s activities). On the far right side of the figure is the “analyst’s world” where tentative solutions to models

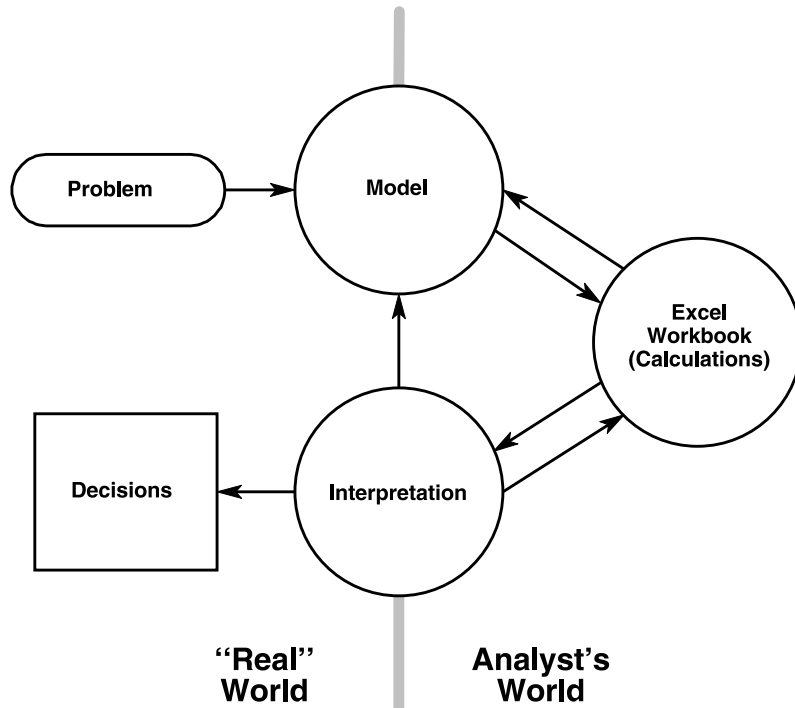


Figure 1.1: Building and implementing decision models.

are generated. Straddling these worlds are the “modeling” and “interpretation” activities, which are the primary foci of this book. Note that arrows circulate among the three activities on the right side of the diagram, indicating that the development and analysis of a decision model is *iterative* in nature: we may modify an existing model based upon our analysis of the calculations generated in EXCEL and/or we modify just how the model is specified in the EXCEL workbook.

Throughout this book, we use Figure 1.1 to indicate which part of the decision process we are examining.

1.3 Spreadsheet models

The focus of this book is on the development and analysis of *spreadsheet models*. We will analyze a variety of managerial problems using an assortment of analytical tools. A common theme throughout the book, however, is the underlying *structure* of the analysis. That structure consists of the following steps:

1. *Develop an optimization model.* We transform a written statement of a problem that requires one or more decisions to be made into an *influence diagram* that depicts the relations among the elements that make up the model. At times, we use these relationships to develop mathematical expressions that result in an optimization model. The solution to the optimization problem results in a recommended course of action.
2. *Develop a spreadsheet model.* Using the influence diagram (and, perhaps, the associated mathematical model) developed in Step 1, we construct a spreadsheet model that facilitates the analysis of the optimization model.
3. *Compute a solution.* We use built-in functions of the spreadsheet software to compute a solution to the problem, i.e. we “solve” the optimization model that was formulated in the first step. This solution constitutes a recommendation as to which decision to implement.
4. *Analyze the optimal solution.* We do not stop with the computation of an optimal solution. We are not only interested in the solution to this *particular* problem. As managers, we seek to understand *why* a particular decision is recommended and how these recommendations depend upon the underlying data and structure of the model we have specified. Developing answers to questions such as “What if . . .” is called *sensitivity analysis* (or *post-optimality analysis*). A spreadsheet is an especially good vehicle for doing sensitivity analysis and is indeed one of the primary reasons for choosing this software tool over many others to do the computations.
5. *Develop a final recommendation.* Based upon the analysis done in Steps 3 and 4, we use the output of the spreadsheet model to generate recommendations the manager can implement in the decision environment (that was described in the problem statement in Step 1).

The emphasis in this book is on *translation* and *interpretation*. We translate the statement of a managerial problem into expressions and relationships that typically result in an optimization model and translate the output of the optimization process back into decisions that can be implemented. We interpret the output of the optimization process and the sensitivity analysis to gain insights into the problem setting that would not otherwise be possible.

We *do not* emphasize computational procedures for conducting the optimization of the underlying model. A discussion of these computational procedures, called *algorithms*, is better suited to an advanced course in management science or operations research designed for students who wish to specialize in this field.

We now illustrate the five-part structure of the analysis laid out above using a simple problem that analyzes whether a copying machine should be purchased or leased.

1.4 A lease/buy problem

1.4.1 Problem statement

The Amiable Insurance Company has determined that it needs additional copying capacity. They are currently negotiating with Sharp Image, who manufacture the X100 copier that meets all of Amiable's technical specifications. The issue is whether Amiable should lease or buy the X100 from Sharp Image.

Given the fairly rapid changes in copier technology, Amiable believes that a current generation copier has an effective life of three years. For the purposes of making this lease/buy decision, they therefore specify a *planning horizon* that has a duration of three years. In general, a planning horizon specifies the duration of a particular decision problem. At the end of this planning horizon, Amiable will initiate a new analysis of its copier needs.

Sharp Image has made the following offers:

- they will *sell* an X100 copier to Amiable for \$10,000;
- they will *lease* Amiable an X100 copier for a yearly fee of \$1,500 plus a usage fee of 7¢ per copy.

If Amiable purchases the copier, they will spend approximately \$800 annually in maintenance fees. (Maintenance costs are paid by Sharp Image if the copier is leased.) They estimate that the X100 will have a salvage value of \$1,000 at the end of three years.

Suppose that Amiable expects to make approximately 50,000 copies on the X100 per year. Amiable's interest rate for discounting purposes is 20%.

Amiable's objective is to minimize the total discounted costs associated with the X100 copier that are generated over the three-year planning horizon. Should they lease or buy the X100?

1.4.2 Influence diagrams

An *influence diagram* depicts the relationships between various elements of a decision problem. The diagram consists of *nodes* connected by *arrows* or *directed arcs*. There are three types of nodes. *Oval nodes* represent (chance) events, an activity that results in an outcome that is not necessarily known at the start of the decision process. In the special case where the event is *deterministic*, so that the value of the node never changes, we represent the oval with a heavy line.

Rectangular nodes represent decisions. *Rounded-corner rectangular nodes* represent final or intermediate values (values of cost, profit, or some other quantity to be optimized).

Arrows connect nodes and indicate the direction of influence that the value of the node at the tail of the arrow has on the value of the node that is at the head of the arrow. The direction of arrow specifies the direction of dependence that one quantity has on another.

Figure 1.2 depicts a simple influence diagram for the lease/buy problem.

Each of the eight ovals in this diagram is drawn with a heavy line, reflecting the assumption that we know with certainty the values associated with each of the events described in each oval. This is a simple diagram since at most one arc emanates from each node: we see that the lease cost per year, lease charge per copy, discount rate, maintenance cost, purchase price, usage, salvage value, and length of planning horizon each directly influence only total cost.

The rectangle labeled “Lease/buy” is the single decision node in this diagram. The decision represented by this node influences only total cost.

The value of total cost is determined by the the eight “oval” events and the single decision. The node that represents total cost is therefore depicted as a rounded-corner rectangle.

The structure of influence diagrams

It is important to realize that the *absence* of an arrow in an influence diagram may convey important information. There is no arrow, for example, from “Usage” to “Lease charge/copy”. It follows that the lease charge per copy

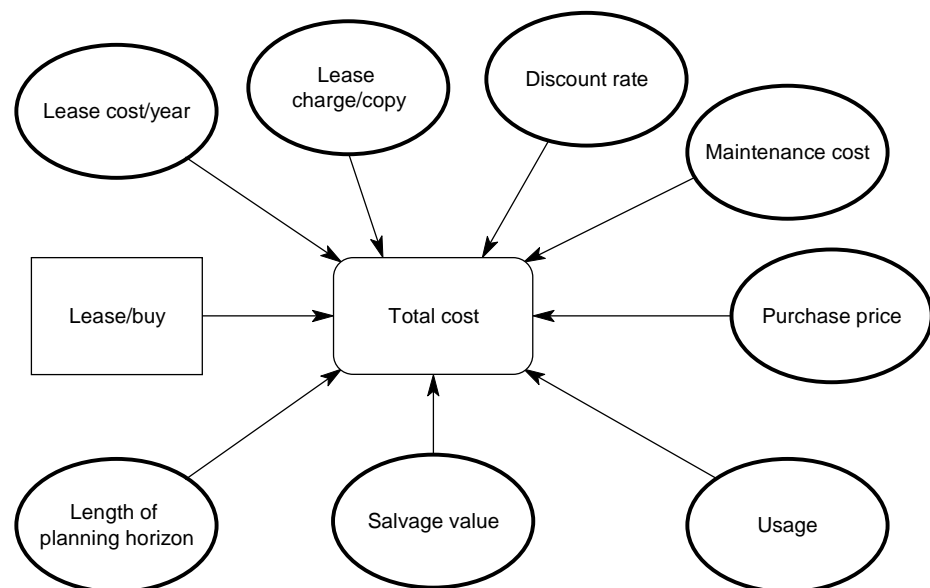


Figure 1.2: An influence diagram for the lease/buy problem.

does not directly depend upon the level of usage. It follows, for example, that Sharp Image is not offering *quantity discounts* to Amiable that would lower the per copy charge if usage exceeds some threshold value.

The *direction* of the arrow conveys important information about the logic of the problem. Note, for example, that the arrow between the decision node (“Lease/buy”) and the “Total cost” starts at the decision node and terminates at the “Total cost” node. The decision to lease or buy *determines* the total cost. The influence is not the other way around. We use total cost as a *criterion* in evaluating decisions, but total cost does not determine which decision is made.

Influence diagrams are *snapshots* of a decision process at a particular point in time. As such, they represent what the decision maker knows or does not know at that particular instant in time. In light of this, it follows that influence diagrams cannot contain *loops*, a sequence of nodes and arrows that form a path which leads back to a node that appears earlier in the path. A loop indicates a “simultaneity” problem of the form “the value of A determines the value of B which in turn determines the value of A”.

There are several things that an influence diagram is *not*. An influence diagram is *not*:

- a *flow chart* that might be used to depict the *sequencing* of activities in a decision process that leads to the determination of some decision;
- a *precedence diagram* that depicts the order in which activities must be executed;
- a *decision tree* (a topic discussed in great detail in Part II of this book) that depicts the *timing* of decisions and their consequences in a decision process. In Part II, we discuss the relationships between decision trees and influence diagrams in more detail.

1.4.3 A spreadsheet model of the lease/buy problem



LeaseBuy.xls

The spreadsheet model for the lease/buy problem is in the EXCEL workbook LeaseBuy.xls, which is on the CD-ROM that accompanies this book. The design of the spreadsheet model and the supporting structure of the workbook is somewhat arbitrary and may be idiosyncratic to the tastes and standard conventions of the designer. A workbook the author has developed for analyzing the lease/buy problem is shown in Figure 1.3. This workbook consists of five sheets, labeled ‘Basic Data’, ‘Model 1’, ‘New Salvage Value’, ‘Model 2’, and ‘Usage Analysis’. The structure of this workbook has the following appealing features:

- Information is grouped logically by sheets. Each sheet is designed for a specific purpose. The sheet labeled ‘Basic Data’, depicted in Figure 1.3(a),