MANAGEMENT DECISION MAKING

Spreadsheet modeling, analysis, and application

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1 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 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 calculations. 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 Sasieni[1] 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. Little[2] 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

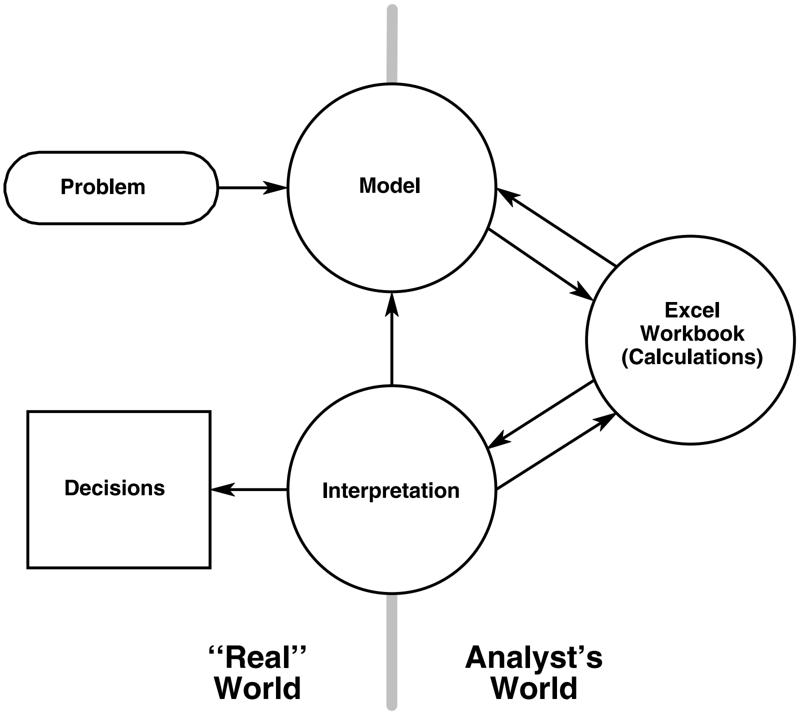

Figure 1.1: Building and implementing decision models.

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

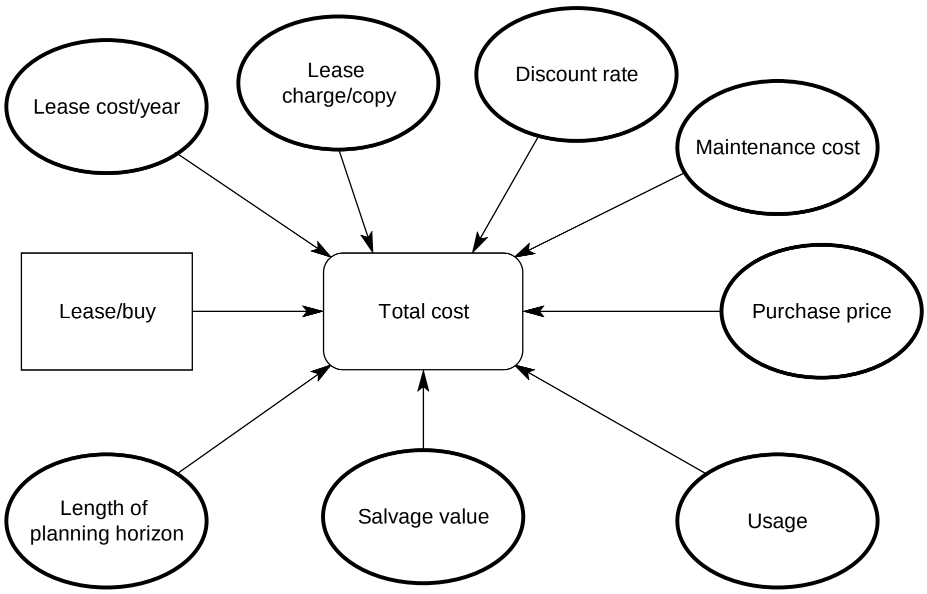

Figure 1.2: An influence diagram for the lease/buy problem.

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),