MODERN DECISION MAKING

A GUIDE TO MODELING WITH DECISION SUPPORT SYSTEMS

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PREFACE

For some time now, the needs of the generalist manager for guidance in creating quantitative models have not been met. Some books prepare people with strong mathematical skills to work as specialists. Other books give generalists an *appreciation* of models, but not the skills to *create* models. What has been missing is a book that can help generalists learn to do their *own* modeling in support of their *own* management responsibilities.

The need for such materials has now become particularly acute and the opportunity especially ripe because of recent developments in computer decision support software and the prevalence of computing power in the manager's office and home. If you need a computer model, you no longer need to hire a consulting firm or bring in company staff to write a model in Fortran. You can create the model in your office and run it in minutes in a high-level modeling language. In this book the examples are done with IFPS (Interactive Financial Planning System of Execucom Systems Corporation, Austin, Texas), but a long list of other financial planning systems available for mainframe computers have similar features. Most of the modeling tasks in this book can be carried out on a variety of software (see Chapter 1) on a microcomputer.

Because English-like expressions are used in the IFPS models, they may be understood quickly. You can change the model as you wish, and the new results will appear almost instantaneously. Even complex problems that formerly may have taken months of labor to write in earlier languages can now be written and run literally overnight or over a weekend.

General modeling languages readily available are now flexible and powerful, and nonspecialists can quickly learn to use them. They tie into large data bases in the firm or available commercially. And they are available for personal computers in high-level languages that are compatible with the same language on a mainframe computer.

This book is intended for two audiences: (1) practicing managers seeking help in developing their own modeling skills on the job, and (2) MBA students and managers in short courses (and advanced engineering, undergraduate business, and public administration students) who will use the book as part of a course. State-of-the-art modeling languages are employed to aid the manager in building a model. But the thrust of the book is not to hammer out solutions to intricate problems, as in the various management science, operations research, or computer science texts oriented toward those who specialize in such fields. Mathematical sophistication is not assumed, yet the book develops skills that enable the reader to use quantitative tools and computation.

The book aims to develop managers' creativity by providing methods and skills that enable them to express their own perception of problems. Powerful tools, such as the influence diagram, enhance the individual's ability to design and communicate models. But modeling is a craft which can only be learned through first-hand experience in carrying out modeling tasks.

Cases provide the context for acquiring these creative skills. Those users of the book in category 1 who will not have the benefit of classroom discussion of the cases, will find study of the book more edifying if they can carry out their own modeling tasks as they read through the chapters and examine the case material. Exercises at the end of chapters (with selected solutions in the back) help the reader to develop some of the skills needed to carry out the larger tasks of the cases. Most of these exercises relate to problems arising from general experience and do not require a special background.

The cases are best suited for students with some experience, or exposure at least, to business problems. They are organized by functional topic into sections such as marketing, finance, planning, etc. after all of the chapters of the book. Practicing managers will easily find the case material that pertains to certain problem areas they may face. The cases were kept separate from chapters to enhance the value of the classroom use of the cases. Often a major task in developing models for decisions is to decide what the problem is and to structure an approach to it. Placing the cases with specific chapters would take away the opportunity to diagnose the problem and the stage of development of the model. In addition, most of the cases deal with material in several of the chapters. There are specific assignment questions related to particular cases at the end of chapters. But this should not suggest that a case referred to at the end of a chapter deals only with the portion of the modeling process dealt with in that chapter. The intent was to provide broadly conceived cases that would help the user of the book develop a holistic approach to problem solving and avoid the pigeonholing of problems which is prevalent in many introductory courses and texts.

It helps if the reader is familiar with introductory business concepts (e.g., the income statement and net present value) in working through the cases. Generally the cases are based on situations in existing corporations. Consistent with the book's philosophy of learning modeling by doing it, the cases each involve a task to be done in the design, creation, and use of a computer model.

In keeping with the purposes of the generalist, a wide range of problem structures is used in the book. Thus, both certainty and uncertainty models are included, with risk analysis integrated into the approaches used when certainty is assumed. Both single-objective and multiple-objective decision situations are treated. In all situations, managers have the flexibility to mix their subjective judgments and preferences with objective data in the model.

The greatest benefit of this book is that it can give generalists, some of whom consider themselves inadequate in quantitative or computer skills, the confidence that they can

1 Develop and run models in time for their own decision making on the job using high-level languages on mainframe and microcomputers.

2 Communicate their model analysis to critical superiors who may have little appreciation for quantitative modeling.

3 Apply a flexible, free-form framework to problems with multiple objectives and uncertain components arising in a variety of functional areas, industries, or firms.

4 Have what may be the most critical managerial skill: the ability to handle messy, unstructured situations using their own preferences and perceptions of the problem.

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I am indebted to the Darden Graduate Business School of the University of Virginia for providing time for me to write this book. The Case Research Program of the Darden School generously provided funds for time, travel, and research assistants for the research and writing of the cases in the book. An award of a Sesquicentennial Associateship from the Institute for Advanced Studies at the University of Virginia enabled me to be on leave for a semester to finish the book.

The book has benefited greatly from the able aid of several research assistants at the Darden School. Michael B. McEnearney worked with me on cases and examples for a year. Michael O'Donnell, William Long, and Jeffry L. McNair each spent a summer developing cases. Not only did they co-develop with me much of the case material, but their thoughts served to focus the ideas of the book and their enthusiasm sustained my excitement with the work.

Many companies and individuals willingly cooperated with the field research needed for the cases. Luckily, there are many managers who recognize the pedagogical benefits of field-based experiences for students of modeling and generously contribute their time and experience, as only they can.

The materials in the book have evolved through use in courses at the University of Virginia, the University of Washington, and in management educational programs of the IBM Corporation. I thank the participants in those courses and faculty members of those universities for their comments and encouragement.

Sherwood C. Frey, Jr., of the University of Virginia deserves special thanks for comments on the content of the book and on the design of courses using the material. Richard P. Ten Dyke of IBM jointly wrote the "DiscoMall, Inc." case, and the following authors are responsible for the respective cases: Elwood S. Buffa, UCLA and James S. Dyer, University of Texas, Austin, for "California Oil Company" case, and Charles A. Holloway, Stanford Business School, for "Westview Environmental Planning (A)." Larry Brown of IBM corporation made a detailed review of an early draft of the book and provided several pages of his own thoughts on modeling, which, with his permission, have been woven into the book. The field work which served as a basis for two of the cases was carried out by Darden School students Charles Barnard ("Stevens and Company") and Robert Martin ("John Denison") as part of a supervised business study done to fulfill educational requirements.

Many people had a chance to correct errors in this book. I have had at least a dozen lunches with students to talk about typographical or substantive criticisms in various drafts. Beverly Seng of the University of Virginia provided editing comments on early drafts. A number of reviewers have examined it. Copy editors have had their chance with it. Spelling proofreaders on my personal computer were used on parts of it. To all of them I am grateful, even to Wang, my Compaq, and my IBM PC for word processing. Yet, I suspect there are mistakes in it still (I am sorry to say) that have gotten by all of us, which your sharp eye may catch. I would be glad to know about the mistakes (I would even be happy to know what you like about the book). Who knows—I may buy you lunch to talk about it.

Samuel E. Bodily

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CHAPTER 1

INTRODUCTION TO MODELING

This book is about creating and using decision models with the aid of a computer decision support system (DSS) For our purposes a *decision model* is any quantitative or logical abstraction of reality that is created and used to help somebody make a decision It consists of quantities and their relationships. For example, if you were considering the purchase of a piece of real estate, you would project revenues and costs over the next 10 years and a residual value of the property after this time and then put this information together to help you assess what the property is worth You may wish to express the relationship of revenues and costs to inflation and then investigate a variety of inflation scenarios. A decision model would contain all of your forecasts and all of the relationships among the variables. It would provide an estimate of the value of the property for any inflation scenario you may envision

A DSS is the conduit for creating, revising, checking, and using the model. In its crudest form, the DSS may consist of a spreadsheet planning system, such as VisiCalc (or one of its many cousins), or an equation solver, such as TK!Solver. Most of the things you might like to do in using this book could be done reasonably well with even the simplest of such software

The professional, however, will quickly develop an appetite for a higher level of decision-making support. Think of the complete DSS as a high-level language that allows for natural, English-like expression of the model; that is able to access corporate and vendor data bases; that has easy-to-use graphics for displaying the results; and that contains powerful computational features for activities such as "what-if," sensitivity analysis, goal seeking, extrapolation, risk analysis, and optimization. In addition, think of the DSS as a system that supports the manager in treating ill-structured, messy problems and extends and enhances the manager's own understanding and judgment rather than providing a unique solution.

The examples in this book use the Interactive Financial Planning System (IFPS)[1], which has all of the features just mentioned in an easy-to-use package that runs on a mainframe computer. A companion package for the personal computer, IFPS/Personal, is fully compatible with IFPS on the mainframe and will run most of the example models in this book. IFPS/Personal does not support risk analysis and optimization and it does not solve problems with the same rich variety of features available on IFPS.

Many other mainframe financial planning systems have features similar to IFPS, and the user of this book could use these systems to carry out the modeling tasks and develop models for the examples. The list of usable systems at the time of printing of this book includes the following:

System	Vendor
CUFFS	CUFFS Planning and Models, Ltd. New York, N.Y.
EIS	Boeing Computer Services Co. Seattle, Wash.
Empire	Applied Data Research Princeton, N.J.
Express	Management Decision Systems Waltham, Mass.
FCS-EPS	Evaluation & Planning Systems, Inc. Houston, Tex.
Foresight	United Information Services Overland Park, Kan.
GSA/GSM	Prediction Services, Inc. Manasquan, N.J.
IMPACT	MDCR, Inc. East Brunswick, N.J.
Model	Lloyd Bush & Associates New York, N.Y.
MSA/FMS	Management Science America Atlanta, Ga.
Simplan	Simplan Systems Chapel Hill, N.C.
Stratagem	Integrated Planning, Inc. Boston, Mass.
System W	Comshare Ann Arbor, Mich.
XSIM	Interactive Data Corp. Waltham, Mass.

There are many software possibilities on the microcomputer as well, too many to provide a complete list. In addition to the many cousins of VisiCalc and IFPS/Personal, the list of microcomputer software available at the time this book went to press would include:

[1]IFPS and IFPS/Personal are registered trademarks of Execucom Systems Corporation of Austin, Texas.

Software	Vendor
1-2-3	Lotus Development Corporation Cambridge, Mass.
Encore	Ferox Microsystems, Inc. McLean, Va.
MBA	Context Management Systems Torrance, Calif.
Multiplan	Microsoft Bellevue, Wash.
System W	Comshare Ann Arbor, Mich.
TK!Solver	Software Arts Wellesley, Mass.
VisiCalc	VisiCorp San Jose, Calif.

This is a book on modeling, not computer language, and it is intended for users of these other systems as well as IFPS users. In most cases the non-IFPS users will be able to understand the IFPS models easily and translate them quickly into the language of their own systems.

1.1 WHY MODEL?

You build a model to help you make a decision or to help someone else's decision. The help comes in two ways. First, the decision maker can respond to much more complexity than one person can easily grasp and resolve. Second, the model, through computer support, can keep track of many details and perform rapidly all of the computations. This allows the modeler to devote attention to judgments made about the individual details and composite results produced by the model.

1.1.1 Necessity

Models are built from necessity. They are done reluctantly when simpler approaches will not suffice. They are not a goal in themselves, even though they can be fascinating, almost seductive in pulling you from the decision at hand.

No one wants a model. People making decisions want the help that models can efficiently give. The model is not part of a goal—the decision is the goal. The model must be limited to a small effort relative to the importance of the decision. Low-stake decisions will be modeled only if they are repetitive or generalizable enough to be levered into a high-stake problem.

Learning to model requires adapting one's language in order to communicate the model and its results effectively. The medium with which to communicate models both to computers and to others is now provided by modern high-level modeling languages. This book adds other design and communication tools to aid the process of translating a messy problem into a model. While it is necessary for many people to become accustomed to new language and certain conventions of communication to create models, few people need to specialize in and study the language.

In this book computer language and mathematics are treated as English would be in a freshman English course; we all need to use English, but understanding language is not a goal in itself, as it might be for an English major. The modeler who is adept in a particular modeling language is like the writer of diplomatic communiqués. The translator can take pride in accurately rendering the subtlety of the subject. Yet neither the language nor the model is the end in itself; they are means to the end of better decisions.

1.1.2 Better Decisions

The model has helped you if you get a *better decision*. The decision can take into account more of the relevant facts and how those facts apply to the decision. The decision can deal with many relationships among things that influence the outcomes of interest. The decision can include the interaction of influences over a much longer period of time so that the decision does not just respond to the most obvious short-term considerations. The decision is better because the model has allowed a sensitivity analysis: The outcome has been studied as different assumptions are methodically varied. The impact of uncertain factors on the surety of results can be understood. The decision maker can understand which assumptions most affect the outcome.

1.1.3 Insight

A model gives you *insight* into your subject. You can explore the balances and tradeoffs among the factors that enter the decision. You learn the structure of the subject—the relationships among influences. It is useful to break a problem into pieces and put it back together in a model just to understand its anatomy. Diagnosis of other problems for which you do not build a model will be better because of this understanding.

1.1.4 Aid to Presentations

A model can be an *aid to presentations*. The model makes explicit the beliefs about interactions of aspects of the subject. Your presentation to the decision maker(s), or your depiction of your own decision, uses that structure. It shows your understanding of the problem as compactly as possible. You can concentrate on the important aspects, as shown by the results of modeling, rather than the obvious aspects.

1.1.5 Intuition

Complex systems behave nonintuitively. The model gives you insight into these nonintuitive behaviors that come from time lags between action and response, from interactions, and from the damping of one influence by another. The model provides *intuition about the whole*, starting with intuition about the parts.

The model tells you which gaps in your knowledge matter. Necessarily, you always work with incomplete understanding and data. Most gaps do not affect the decision much, but your model analysis tells you which pieces of information are important. This sets your agenda for research. If time and money allow, you know which areas of study will most improve the quality of the decision.

1.2 A MODELING DISCIPLINE

The model must be reliable. It must accurately reflect the assumptions of its builder. A disciplined development of the model is essential. The rest of this chapter describes such a discipline, one that works well. Subsequent chapters develop the elements of that discipline piece by piece.

1.2.1 Simplicity

The model must be kept simple, both to help make it reliable and to limit the investment in it. The model should be extendable. New influences may need to be taken into account and new questions may be asked about the subject matter of the model. Thus the process of model building recognizes two facts. First, the model will grow and shrink in future uses; thus the modeler must use tools that allow flexible editing. Second, a useful discipline for modeling cannot be described in terms of a flowchart. It is impossible to include all of the branching points in which it may be necessary to go back and redo a previous stage of the process or skip ahead to a later stage and work backward. Two important watchwords are *simplify* first-cut efforts to the bare essentials and *reconsider* any structure already applied to the problem in going on with the process.

1.2.2 Communication

A modeler must communicate with a computer that runs the model. This is the least important form of communication. More importantly, model builders communicate with themselves, through the model, about the structure of the subject that is modeled. The model must be clearly written so it can be quickly understood. This clarity also helps make the model reliable.

The model also provides communication to other people. It represents the embodiment of the beliefs of those who developed its structure; its clarity is essential.

1.2.3 The Manager's Roles in Modeling

A full appreciation of the specific purpose of the discipline requires an understanding of the relationships between the manager and the model. Throughout their careers, managers will work with decision models in three roles. The manager serves as model builder and *analyst*, as initiator and *user* of the model, and as the model's beneficiary or *client*. These roles are illustrated in the Stevens & Company case in this book. In that case a real estate firm that brokers large estates and agricultural properties is interested in modeling a large timber and farm property for prospective investors. The company engages a student of a master of business administration (MBA) program to carry out the modeling work. In this situation, the MBA student is the analyst, the broker is the user, and the prospective buyer of the property is the client.

While settings of problems may vary, these roles are generally identifiable in virtually all problems, although one person may play more than a single role. The Unicron cases illustrate the roles in a corporation, for example. A financial staff member is the analyst, the vice president of finance is the user, and the members of the new products review committee (senior executives) are the clients.

Typically, MBA graduates play the role of analyst more often in the early years following graduation. As they move up in the organization, they take on a greater portion of the user role (and have analysts reporting to them). As they become responsible for more and more decisions, they increasingly are clients with respect to the models.

Each role requires separate skills and an appreciation of the tasks faced by those in the other roles. As a user, the manager will learn to define objectives and performance measures for decision making, to structure the variables that will be used in the model, and to evaluate and use the support offered by the model. As an analyst, the manager will learn how to write the model; how to carry out the assessment of numbers needed in the model; how to conduct an analysis of any combination of certain, risky, and time-dependent variables; and how to communicate to supervisors the work done on the model. In both the user and the analyst roles the manager will need to know how to present the model design and results to clients. As a client, the manager will learn to *evaluate* and understand the work of others and learn appropriate ways to *intervene* in the modeling effort.

The skills necessary to be effective in each of these three roles are developed in this book. The discipline of modeling is described assuming the reader is interested in learning all three roles. Indeed, in many of the cases in the book, proper understanding of the situation and the appropriate tasks to carry out requires that the problem be examined from the perspective of each role.

1.3 GETTING STARTED

Managers often have the greatest difficulty knowing how to start a model. Their problems may appear to be huge and untidy, and they may have little confidence and experience in creating a model. Thus a major focus of this book is model structuring.

How do you start modeling? First, understand the decision that is to be made. This sounds simple, but very often a problem is so complex that no one has clearly stated what they are trying to decide. This phenomenon was illustrated vividly to me in working with executives on a new-product-development problem. Although this was a big project on which many people had already done a lot of planning, I could not get them to tell me what the decision to be made was. It might have been a go or no-go decision on the product, or it may really have been a product redesign question since the commitment to the product in some form appeared firm. Although a lot of time and work had already been spent on the problem, no one was sure exactly what the decision was to be made and what were the available alternatives. In that case, a little time spent defining the questions at the outset could have saved an enormous amount of time later.

Finding the objectives to be achieved in making the decision is not always obvious or implicit in the decision. Make sure what is being maximized before creating a model to decide how to do it.

Chapter 2 presents ways to define decision variables, to establish the objectives of decision making, and to identify attributes associated with the objectives. A key contribution of this material is the assurance that it can give the modeler that the objectives of the decision maker can be translated into attributes that measure the degree of achievement of the objectives.

Having identified the variables of a model, the next step is to decide how these variables relate to one another. Chapter 3 presents tools for structuring a model design from the variables. The influence diagram displays all variables, and arrows running from one variable to another indicate the direction of influence. Variables that are assumed to be known with certainty are distinguished from those that are uncertain.

The diagram also uses three distinctive types of influence. The simplest influence is one where the level of one variable determines the level of another variable with *certainty*. A *random* influence implies that a variable only partially affects the level of another and an unpredictable effect also partially determines the level of the influenced variable. The final type of influence is a *preference* influence, wherein the desirability of an attribute is influenced by another variable or attribute.

The step of creating the influence diagram is the most important one in establishing the framework of the model. Often you find a "major" influence is not linked to an attribute at all. When this occurs, demote it to a minor consideration to be handled outside the model. Sometimes holes in the influence diagram indicate that intermediate variables are missing. Not only does the finished influence diagram make you ready to get down to the nitty-gritty of writing the model, it is the most convenient form for presenting the model to others.

1.4 CREATING AND USING A MODEL IN A HIGH-LEVEL LANGUAGE

The next step is to decide on the form of relationship for each influence. Keep relationships simple; there is no prize for introducing the most unusual mathematics. Later steps of the modeling discipline will revisit these choices and you will have an orderly way to improve the ones that matter.

This does not mean that within the bounds of simplicity and conciseness the model should not be as accurate a representation of reality as possible. The modeler needs to become familiar with the wide range of possible relationships among variables that may be expressed in order to create realistic models. Chapter 4 describes a menu of mathematical functions to use in expressing a relationship between a dependent variable and one or more influencing variables.

The examples use the features of IFPS, but the modeling capabilities are available on most high-level planning or modeling languages. Most relationships can be produced with a little effort even on microcomputer spreadsheet planning software.

Random variables are modeled with a menu of available probability distributions. When random variables are used, the models are solved using the technique of Monte Carlo simulation (described in Chapter 5) in order to see the uncertainty in the attributes.

Chapter 5 describes how to complete the model to obtain preliminary results and then how to improve and validate the model. After checking the pieces of the model, you test the accuracy of the model in its composite form. A first-cut run of the model is the place to begin.

What-if exercising helps in understanding and verifying the model and provides answers to decision questions. Sensitivity analysis continues this process, revealing the significance of intermediate variables in determining attribute levels. Use this understanding to decide if and how to extend the model.

At this stage, you can test specific goals using the model. For example, you can check whether it is possible to attain some target level of performance on a specific attribute. This begins to move the problem from the realm of what if to the realm of "what's best." A what's-best analysis requires evaluating the relative desirability of alternative levels of outcome attributes. This raises questions of how to treat multiple objectives and uncertain attributes.

1.5 INCORPORATING DECISION PREFERENCE INTO MODELS

Chapter 6 describes the major ways to make choices accounting for multiple objectives. Starting with dominance and other approaches that do not require tradeoffs among attributes, the chapter goes on to describe procedures for weighting attributes. These procedures are easily incorporated directly into a model.

Chapter 7 provides the modeler with methods for incorporating attitude toward risk into the model. An important aspect of the approach of this chapter is the discussion of how to treat risk when one is modeling corporate risk preferences, where there is no single person to express attitude towards risk.

The modeler may want a more realistic model of preferences than was provided in Chapter 6. In particular, it may be necessary to treat interactions among attributes and nonlinear values for attributes. For example, an attribute such as square feet of space in a model to help in choosing a home may be such that its value is nonlinear. That is, the value of an additional 100 square feet of space may decline as the size of home increases. Preferences for this attribute may interact with another variable or attribute. For example, the location of the house may greatly affect the desirability of various home sizes. These issues are treated in Chapter 8. Besides discussing the implications of the various preference models, the chapter gives guidance on assessing preferences.

The final two chapters deal with specific application problems. Chapter 9 shows how to use models for group decision making. The principal application of this would be to the committee decision problem, but more general collective choice problems and bargaining problems are considered. Voting rules, scoring rules, procedures for achieving consensus, and group preference functions are presented and incorporated into decision models.

Chapter 10 treats issues that arise when modeling risky projects that stretch over significant amounts of time. Several approaches are described. The discussion then centers on when and why each possible approach should be used.

The discipline developed in this book will prepare you to take an unstructured problem, decide on the important variables and attributes, structure influences among these variables, apply your own or a group's preferences to them, exercise the model, and make a decision. What is then needed is familiarity with a wide range of applications and some experience developing models in a decision context. The cases making up the rest of the book provide this opportunity to internalize the discipline.