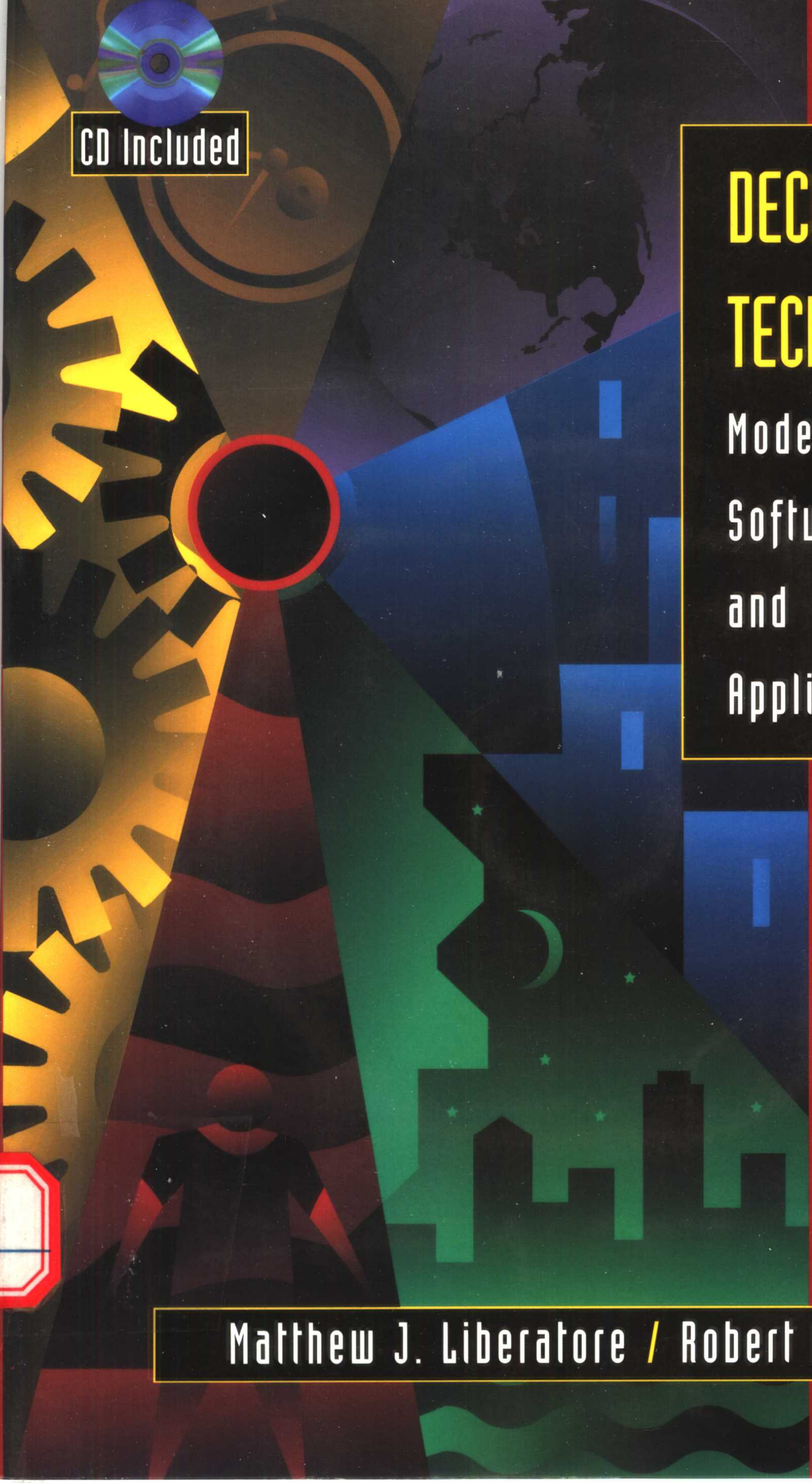

DECISION TECHNOLOGY

Modeling, Software, and Applications

Matthew J. Liberatore / Robert L. Nydick

Decision Technology
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Matthew Liberatore
Villanova University

Robert Nydick
Villanova University

John Wiley & Sons, Inc.

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Foreword

Every age sets the definition of what one must learn to be considered an educated person of the time. Medieval scholars pondered the seven liberal arts: grammar, dialectic, rhetoric, geometry, arithmetic, music, and astronomy. Most early American colleges set out to train students for the ministry or for service to the state. Many of these academic institutions offered a "broad plan of education" that included a great deal of mathematics, science, government and law. Post World-War II students, especially after the launch of Sputnik, and today's students who have grown up with the Internet, have seen such broad plans to be vague and ever-changing. Universities have become caught up with teaching what is hot and dropping what is not.

What an educated person must know in the 21st Century is somewhat muddled. But, to me, based on the scientific, mathematical, and computational advances of the last half of the 20th century, today's educated person must acquire a knowledge and understanding of what Professors Liberatore and Nydick term *decision technology*.

Decision technology may be viewed as an integration of mathematical theory and computational techniques that combine to form an ever-expanding set of proven decision aids for just about all areas of business, industry and government. Each day you are the beneficiary of decision technology: the supermarket's shelves are stocked with the products you want when you want them; your mutual fund manager decides what to buy or sell and when; your company decides where to locate a new retail outlet; your new house is built on schedule; the time you wait in line at the bank or post office is shorter; your search of the world-wide-web turns up a low-cost airfare for a sudden trip.

Decision making is often a personal and lonely affair. You have choices. You have to decide on whether to take the "road less traveled," or to take the left fork or the right fork along the road of life. You can't fall back on Yogi Berra's advice: "When you come to a fork in the road, take it." The outcome of a road or a fork not taken is never known. Once a decision is made, you have to live with its consequences. You can never claim that your decision was the "best." Although your experiences and judgment help you to make a decision, you will find that the results a decision technology analysis will broaden your view of the road and enable you to make a more confident choice.

Decision technology is a true product of our time. Although based on advanced scientific discoveries, it is distinguished by its use in the everyday world of commerce and industry. Professors Liberatore and Nydick make this clear by describing how four of the main topics of decision technology can improve decision making in a wide range of applications. The four topics—mathematical programming, decision analysis, simulation, and project analysis—cover a major portion of the total field.

The authors have coalesced their many years of teaching and applying decision technology into a text whose material is student friendly and classroom tested. Their pedagogical approach uses software (designed and produced by specialist companies and included in the text's CD) that facilitates the student's ability to put the technology to work. As they note: ". . . the focus of this text is on the application and not on the mathematical details underlying the models."

The educated person of the 21st century must have an understanding of decision technology. Decision technology contributes greatly to the well-being of the U. S. and global economies. A knowledge of decision technology will make you a better employee, a more valued manager, and, a more informed citizen of the world. *Decision Technology* is an excellent guide for your travels along the fork-filled road that leads to the future.

Saul I. Gass
Professor Emeritus

Robert H. Smith School of Business
University of Maryland

Preface

Decision technology is the application of decision-support modeling and computer software to problems in business, government, and other types of organizations. Decision technology is closely related to, and has its origin in, the field of management science. The purpose of this book is to enable advanced undergraduate and graduate students to learn the essentials of modeling with software so that they can create and implement models to support organizational decision making.

This text provides an understanding of the core concepts and ideas underlying the techniques presented so that intelligent decisions can be made concerning how and when specific models and software packages are appropriate. However, the focus of this text is on the application and not on the mathematical details underlying the models. What makes this book different from many others is that we attempt to integrate the discussion of the theory with its application through modeling software. This text's use of Microsoft Project 2002, LINGO, Expert Choice, and Extend Software, instead of spreadsheets, sets it apart from other textbooks.

The text of *Decision Technology* is organized into parts and addresses four of the most important classes of modeling techniques: mathematical programming, decision analysis, simulation, and project analysis. Within each part, an example is covered in detail that provides a solid foundation for building additional models. The text supports the development of modeling skills by emphasizing how the various examples contain components or blocks that can be combined or modified to address other more complex problems.

SOFTWARE

One or more modeling software packages are applied to various problems within each part of the text. These packages are: LINGO (LINDO Systems Inc. 2001) for mathematical programming; Expert Choice (Expert Choice Inc. 2000) for decision analysis; Extend (Imagine That Inc. 2001), and Stat::Fit (Geer Mountain Software Corporation 2002) for simulation; Microsoft Project 2000 (Microsoft Corporation 2000) for project analysis; and Excel as an interface with LINGO and Extend for data input, model output, and for illustrating project analysis methods. The text is bundled with a CD that contains student versions of LINGO, Expert Choice, Extend, and Microsoft Project 2000. The CD also has a folder that contains all of the model files that are presented in the text.

INSTRUCTOR FLEXIBILITY

Each part of the text is self-contained, so that the instructor can select the combination and order of the parts in order to meet their teaching needs, whether for a quarter or semester course. In the mathematical programming section, after completing Chapters 2 and 3, those instructors choosing to use the LINGO modeling language would use Chapters 4, 5, and 6 and skip Chapters 7 and 8. Those instructors preferring LINGO's standard algebraic approach would skip Chapters 4, 5, and 6, and cover Chapters 7 and 8. Appendix A: Statistical Concepts, serves as reference material for Part 3: Computer Simulation. Appendix B: Summary Description of All Extend Blocks Used, also provides a useful reference for Part 3. The mathematical prerequisite for this text is a course in algebra. In addition, it is assumed that the student has at least a working knowledge of Windows.

ANCILLARY TEACHING MATERIALS

The following support materials are available to the adopting instructor from the publisher at:http://www.wiley.com/college/liberatore or by calling (877) 762-2974.

- **Solutions files:** prepared by the authors, includes computer model and Word files for all homework problems in the text.
- **PowerPoint presentation slides**: prepared by the authors, includes an extensive set of charts for all chapters.

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We would like to offer a special note of thanks to our students who have used preliminary versions of this text during the past several years. These students were drawn from our professional part-time MBA, Executive MBA, and undergraduate programs. Many of these students reported successful applications of the methods to problems within their own organizations. Their feedback has helped to direct this text to meet the needs of today's practicing managers.

We would also like to thank our former student, Jeannette Kelley, for continued interest in our book, suggestions to improve the text and some support materials, and substantial contributions to Chapter 16. We would like to thank Elaine Webster for accepting the challenge and writing a self-contained appendix on statistical concepts.

We offer a special note of appreciation to Expert Choice, Imagine That, LINDO Systems, and Microsoft for allowing us to bundle their software with our text. In particular, we would like to thank our friends Dave Krahl at Imagine That, Mike Jones and Rozann Whitaker at Expert Choice, and Mark Wiley at LINDO Systems for believing in the importance of developing a text that integrates modeling, software, and application.

We also would like to thank Lorraina Raccuia, Editorial Assistant and Caroline Sieg, Senior Production Editor, for their efforts and support during the preparation of this text. We are also indebted to our editor, Beth Golub, for believing in us, sharing in our vision, supporting our efforts, and for having the courage to see *this project through* to its completion.

Table of Contents

*Chapter 5 and 6 use the LINGO modeling language approach; Chapters 7 and 8 cover essentially the same material, but use the standard algebraic LINGO approach. Therefore, skip Chapters 5 and 6 *or* 7 and 8 per instruction from your professor. See the Preface for further details.

Chapter 1

Introduction

DECISION TECHNOLOGY, MANAGEMENT SCIENCE, AND MODELING

Overview

Decision technology is the application of decision-support modeling and computer software to problems in business, government, and other types of organizations. It is a value-added activity dedicated to improving the quality of the decision-making process. The benefits of decision technology include identifying and valuing potential problem solutions and offering penetrating insights into the problem's structure and interrelationships. Knowledge of decision technology is critical—to understand today's and tomorrow's business and industrial worlds one has to have knowledge of how decisions are made and how decision technology can play an important role in supporting the decision-making process.

Decision-aiding models can often be expressed in mathematical terms. For this reason, decision technology is closely related to, and has its origin in, the field of *management science,* also called *operations research.* Management science is a scientific approach to decision making that often uses *mathematical models* to help formulate and solve problems or to gain insight into them. Simply stated, a mathematical model is a representation or an abstraction of a real situation or system. The model does not seek to incorporate every possible factor or relationship present in the real world, but only those needed to adequately address the salient relationships. An example of how a simple model can provide a counterintuitive solution to an interesting problem is given in the appendix at the end of this chapter.

The steps in the modeling process are summarized in Figure 1.1. Problem formulation is critical since it drives the rest of the process, beginning with model development. Interestingly, solving the model is often the easiest part of the process, when performed by a knowledgeable user with good software support. The validation step ensures the adequacy of the "fit" between the model and the reality it seeks to represent. Finally, the modeling effort is completed with its usage or implementation. A successful implementation is one in which the model solution is either directly used by the decision maker, sometimes called a "classic implementation," or one that provides added value through organizational change. Examples of organizational changes include improved coordination and communication patterns, and knowledge creation and dissemination concerning the organization's processes and routines. See Liberatore et al. (2000) for more discussion of classic implementation and modeling and organizational change issues. Lastly, feedback allows the modeler to return to an earlier step in the modeling process to make adjustments as needed.

Breakeven Example

The following equation is a simple model of total profit (P) for a firm:

$$P = 25x - 200$$

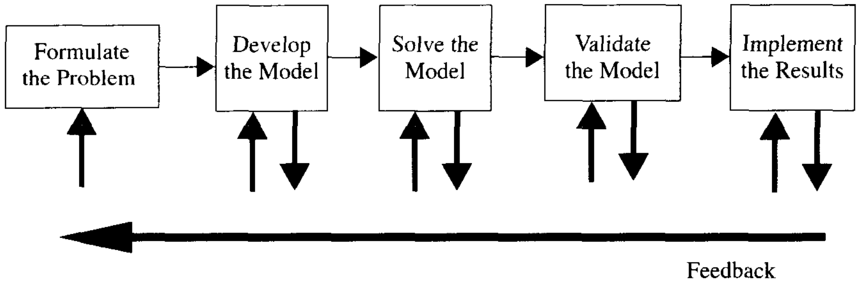

Figure 1.1 The Steps in the Modeling Process

where x represents number of units sold, the contribution margin (unit revenue minus variable cost) is $25, and the fixed cost of production is $200. This model shows that as x increases from 10 to 20, P increases from $50 to $300. However, certain factors may have been ignored in the development of this model. Examples include the costs associated with items produced but not sold, some price discounting when a large number of units are sold to one customer, and variable costs changing according to fluctuating materials costs. However, the model may be at a satisfactory level of detail for estimating the breakeven volume for this product (that is, the volume at which the fixed cost is recovered from product contributions).

Specifically, this model indicates that the breakeven volume is 8 (200/25) units. In addition, the model also shows that if the contribution margin were to be decreased by 20%, the breakeven volume would only increase to 10 units (200/(.8 * 25)). The 20% potential decrease may be sufficiently large to include the possible downside factors already mentioned that were ignored in the formulation of this model. As a result, this simple model may be adequate if knowing that the breakeven volume is likely to be in the 8–10 range and is therefore sufficient for the particular decision at hand. The interested reader is referred to Anderson, Sweeney, and Williams (2000), Clauss (1996), and Eppen et al. (1998) for more detailed discussion on modeling activities in management science.

MODELING TECHNIQUES

Management science is often associated with a body of modeling techniques that find frequent application. This book addresses four of the most important categories of modeling techniques: *mathematical programming, decision analysis, simulation,* and *project analysis.* These four categories were chosen because they are key to the resolution of a wide range of decision problems. We have decided to go into more depth in each of these topics at some sacrifice to the breadth of modeling categories covered. This book is organized into parts, each containing several chapters devoted to each topic. What makes this book different from many others is that we attempt to integrate the discussion of the theory with its application through modeling software. The purpose of this book is to empower students to model a broad range of practical problems.

Mathematical Programming Mathematical programming considers the problem of allocating limited resources among competing activities. These resources could be people, capital, equipment, or materials, whereas the competing activities might be products or services, investments, marketing media, or transportation routes. The objective of mathematical programming is to select the best solution from the set of solutions that satisfy all of the restrictions on the resources. The chapters on mathematical programming cover problems in which the relationships among the factors are either linear or nonlinear, and the factors themselves can take on either continuous or integer values. The reader has the choice of using either the standard algebraic approach or the modeling language approach to study important mathematical programming applications. Commodity flow networks and related problems are not covered. The interested reader is referred to Bazarra, Jarvis, and Sherali (1990), Hillier and Lieberman (2001), and Winston (1995) for coverage of these topics and further discussion of mathematical programming.

Decision Analysis Decision-making methods such as classical decision analysis and the Analytic Hierarchy Process (AHP) provide structure and guidance for thinking systematically about making complex decisions. Examples include which job offer to accept, where to locate a new service facility, and whether a local government should offer a tax amnesty program to increase revenues. Decisions such as these are characterized by uncertainty, conflicting multiple objectives, and differing perspectives of the various affected stakeholders. The chapters in this module focus on the AHP, which uses comparative judgments to analyze decision problems expressed in terms of their goal, decision criteria and alternatives. Readers interested in a more detailed discussion of utility theory or in a discussion of decision trees should consult with Clemen (1996), Samson (1988), and Keeney and Raiffa (1976). Saaty (1996) is a good source for a more in-depth treatment of the AHP.

Simulation Simulation allows the modeling and analysis of complex, real-world systems, when one or more variables or relationships are probabilistic. A simulation model consists of a set of mathematical and logical relationships that describe the operation of the system. Probabilities are used to randomly generate the occurrence of system events, such as arriving customers, and the time needed for system activities, such as a banking transaction. A course of action is evaluated by simulating the operation of the system over an extended period of time. For example, waiting-line or queuing statistics at a bank could be estimated by simulating 1000 days of operation. The chapters in this module focus on process simulations but consider financial simulation as well. Readers interested in obtaining more information about simulation should consult Banks, Carson, and Nelson (1995), Law and Kelton (1991), Pidd (1998), and Thesen and Travis (1991). More details on financial simulation using spreadsheets can be found in Winston (1998). Analytical queuing is not covered in this text, and readers are directed to Gross and Harris (1998), Prabhu (1997), and Kleinrock (1975) for this topic.

Project Analysis A project is a temporary endeavor undertaken to create a unique product or service. Projects are comprised of a set of logically related activities or tasks that lead toward a common goal. Examples include building a warehouse or a ship, developing software or an advertising campaign, and implementing new technologies or work procedures. The chapters in this module focus on determining the project schedule that will allow the project to be completed as quickly as possible, and on analyzing the impact of resource limitations on project completion. Good heuristic (scientific "rule of thumb") procedures are presented to address resource constraints, and to identify the least-cost approach to expedite the project. Other managerial topics such as project organization and control are not addressed here. The interested reader is referred to Meredith and Mantel (2000), Mantel, Meredith, Shafer, and Sutton (2001), Cleland (1999), Kerzner (2000), and Gray and Larson (2000).

Each of the modules addresses the theoretical underpinnings of the models covered. We emphasize understanding key concepts rather than the details of specific algorithms. In each module, one example is covered in detail to provide a solid foundation for building additional models. Also, one or more modeling software packages are applied to various business problems within each module. These packages are: LINGO (LINDO Systems Inc. 2001) for mathematical programming; Extend (Imagine That, Inc. 2001), and Stat::Fit (Geer Mountain Software Corporation 2002) for simulation; Expert Choice (Expert Choice Inc. 2000) for decision analysis; Microsoft Project 2000 (Microsoft Corporation 2000) for project analysis; and Excel as an interface with LINGO and Extend for data input and model output, and for illustrating project analysis methods.

MODELING SOFTWARE VS. SPREADSHEETS[1]

Electronic spreadsheets are an alternate approach to modeling software. A compelling reason for using spreadsheets is the fact that there are "thirty million users" and that "spreadsheets have overwhelmingly become the analytical vernacular" (Savage 1997, p. 43). Today there are many products and spreadsheet add-ins such as Solver bundled with Excel and What'sBest!, both for optimization; @RISK and Crystal Ball for simulation; and INSIGHT.xla for optimization, decision analysis, and simulation (Savage 1998). These products facilitate the application of management science. In addition, spreadsheet objects, such as one developed for transportation routing, are shipped with roughly a million copies of Excel each year and can be combined with other objects to create additional management science applications (Savage, 1997). All of these are important advantages offered by spreadsheets.

The disadvantages of spreadsheets include their limitations relating to documentability, scalability, and hyperscalability (Savage 1997, 1998). Documentability is the ability to document a spreadsheet model for ongoing maintenance and use by others. Scalability is the ability to change the number of items in a set of the model, for example, the number of products within a production-planning model. Hyperscalability is the ability to add or remove dimensions of the model, such as adding a time dimension to a static production-planning model.

In the past, we have experimented with the use of spreadsheets and have encountered scalability and hyperscalability problems. For example, when we experimented with spreadsheet simulation and the available add-ins, we found that it was difficult for students to address the queuing and process-redesign situations that often occur in practice. One could argue that additional add-ins are needed and perhaps could be developed. However, we want to empower students to model the situations and behaviors that interest them. Visual simulation software packages, such as Extend, do this. Therefore, for model development and pedagogical reasons, we have adopted the use of modeling software for the applications covered in this text (see also Gass, Hirshfeld, and Wasil 2000).

The students' learning curve in using some modeling software packages is steeper than with spreadsheets. Although spreadsheet modeling is initially easy, it quickly becomes difficult to create complex models. In contrast, once the student achieves a certain level of understanding with the modeling software, he or she can easily develop more comprehensive models. In this book we will focus on helping students to learn the essentials of modeling with the software so that they can create and implement their own models.

BECOMING AN ACTIVE MODELER

Prior to the development of user-friendly modeling software, only specialists generally applied management science techniques such as those mentioned previously. For this reason, the goal of introductory management science courses was to enable students to

[1]The remainder of this chapter is largely based on Liberatore and Nydick (1999).

become *intelligent consumers* of management science. Today, while being an intelligent consumer is still important, the goal of decision technology is to empower students to become *active modelers*. This goal is now possible, in part, due to the power, flexibility, and ease of use of modeling software (to be discussed later).

In addition, the focus is now on the application of models and *not* on the mathematical details underlying the models. This does not mean that we can or will ignore the mathematical foundations and important concepts underlying the techniques used. However, our goal is to have enough understanding of the "black box" so we can make intelligent decisions concerning how and when specific models and software packages are appropriate. This results in a paradigm shift: the focus changes from what *could and would* be done with management science to what *can and will* be done with decision technology. The *can and will* comes about primarily by applying decision technology to actual problems faced by organizations. For this reason, project work can be an integral part of the decision-technology course.

DECISION-TECHNOLOGY PROJECTS

In our experience, many decision-technology applications arise in service-based organizations and address problems in finance and marketing as well as operations. Regardless of origin, a successful implementation occurs if the project genuinely causes a positive change, or demonstrates relevance through positive feedback from management. The journal *Interfaces* is a source of completed management-science and decision-technology applications. Examples of recently completed student projects applying mathematical programming, decision analysis, and simulation follow. Project analysis is not addressed, since this material was recently added to this text.

Mathematical Programming

Typical mathematical programming projects have focused on job, production, and employee scheduling; transportation and traveling salesperson problems; site location; capital budgeting; menu planning; Markowitz financial portfolio analysis; and financial planning.

1. Many groups applied mathematical programming to job- and staff-scheduling problems. For example, one group developed a model to schedule the generation of circulation lists for bulk mailings. The firm intends to use the model in the upcoming quarter and compare the results with the current manual process. A second group implemented a production-planning and scheduling model. It is being used to suggest line-balancing options and to analyze alternatives for adding a new assembly line. A third project team implemented a model that recommended changing staff assignments across all shifts. In addition, based on the model's recommendations, the firm also added a Saturday shift on a trial basis. A fourth implemented staff-scheduling model supported a request to increase staffing levels at a financial services firm. A fifth implemented staffing model is used to plan weekly staff assignments of health-care professionals for a national leader in physical-rehabilitation services.
2. A major bank holding company whose primary business is credit card lending must determine the proper mix of funding to support operating needs. One student group developed a linear programming model to address this problem and found that their results were within 2% of a forecast generated by an in-house software system. The company's asset/liability group agreed to use the model as a baseline for comparative purposes.

3. Several groups have successfully applied the Markowitz financial portfolio model. One group obtained results similar to those obtained by their bank's proprietary portfolio software. Another group developed a two-phase model in which they used a variety of financial factors to screen potential investments and a Markowitz model to decide on the level of funding for those investments passing the initial screen. Management is considering applying the model. Another project team formed an investment club based on the application of the Markowitz model. They described their approach to the account administrator of another club, who reacted enthusiastically and expressed regret that the students had not joined his club!
4. One group expanded upon the diet-planning model that we developed in class and applied it to an organization of 15 adult communities in three states that serves over 4.4 million meals per year. Additional constraints included limitations on consecutive selection of entrees and meeting a minimum satisfaction level. Management was extremely satisfied with the model's results, but wanted to address how to handle leftovers and how to improve computerization before proceeding with implementation.
5. An unusual and interesting example was an effort to develop a model to minimize the number of transport multiplexes cable television companies will need to meet forecasted demand for a service called near video on demand (NVOD). With NVOD, cable companies compete directly with video rental stores by broadcasting each movie in the offering list several times on related virtual channels. As a result of their modeling efforts, the students made several recommendations on ways to improve the LINGO modeling language, which we sent to LINDO management. LINDO systems' vice president for research and development responded,

   Their [the student's] suggestions for enhancements to our LINGO package were well thought out and insightful. It is an honor to us to realize that users have taken considerable time and effort to carefully evaluate one of our packages. We'll do our best to see if we can address your students' concern in upcoming releases.

Decision Analysis

Typical AHP-based projects have concerned: prioritizing alternatives and resource planning, including product, project, and job selection; employee evaluation systems; facility location; vendor selection; and transport mode or carrier selection.

1. One group used Expert Choice to evaluate and select money-market funds for investing a Fortune 100 company's surplus cash. The evaluation criteria include yield (gross yield and fee), safety (funds ratings, diversification of cash portfolio, and funds age), liquidity (fund asset value and deadline for purchases and redemptions), and the relationship of the fund provider to the company (participation in a revolving credit facility, other business with the company, and the funds sales effort). The group presented the top-rated four funds to the treasurer, who approved the selection and now uses the model to invest the firm's surplus cash, which average $150 million.
2. Several groups have successfully applied AHP to a variety of human-resource-management problems, including redesigning employee-appraisal systems, allocating salary increases, and employee hiring. During the past year, one group tackled the annual evaluation of hourly warehouse employees in a family-owned-and-operated wholesale distribution business. One of the students was a principal

in this business and led the development and testing effort using the AHP ratings approach. After a presentation to the other three principals of the business, the four principals unanimously decided to implement the AHP-based system. A second group developed an Expert Choice model for hiring new employees. The model received positive feedback but could not be immediately implemented because of a large merger. However, the director of professional practices plans to present the model to the merged company.

3. In a number of projects, students have addressed problems in the medical and pharmaceutical fields. For example, several groups have evaluated how to allocate research and development (R&D) resources to competing projects. (Some of these projects are based on the ideas presented in Liberatore (1987).) One of these projects is under consideration by a large pharmaceutical company. Another group project led to further work for one of the group members who successfully implemented an R&D resource allocation method after completing an independent study. This effort also resulted in two publications (Ross and Nydick 1992; Ross and Nydick 1994). In a third project, a group used AHP to evaluate applications for a biomedical research award at a major university. The project was modeled after a project of ours (Liberatore, Nydick, and Sanchez 1992) and was implemented immediately. Another project focused on the selection of surgical residents at a major teaching hospital. This course-related project led to a follow-up independent study project. The resulting selection procedure was implemented and published (Weingarten, Erlich, Nydick, and Liberatore 1997).
4. Another group applied the AHP to evaluate proposals for new projects to support the global food-service business segment of a large international food products firm. The company has tested the model and compared its results with those obtained by the current evaluation process. Based on the favorable results obtained, the company formed an evaluation team to conduct additional testing. In addition, the group recommended adding Expert Choice to the firm's software product suite. It is preparing a report to obtain senior management approval of the model approach and the software purchase.
5. One group used the AHP to evaluate and select investment banks that underwrite securities being structured for the bank's small business clients. The treasury department of this firm decided to run the Expert Choice model in parallel with its current selection process to test the validity of the results. If the findings are favorable, the firm plans to implement the model. In addition, managers asked the group to provide guidance on revising their model for parallel testing by a different business area within the company. In a similar project, another group used the AHP to evaluate a set of growth funds offered by a major mutual-funds investment firm. The firm received the group's results favorably, and the firm is doing additional work to refine the model's criteria and weights. In addition, the company is evaluating the possibility of offering its clients the opportunity to use an AHP-based approach to individually select funds over the World Wide Web.

Simulation

Typical simulation-based projects have focused on various queuing or waiting line applications. These included call center operations; supermarket, bank, fast food restaurant, and turnpike service systems; and miscellaneous applications such as staffing levels, production capacity planning, and loading-dock performance.