The Teachers' Forum: Breaking the Mold—A New Approach to Teaching the First MBA Course in Management Science

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Much has been said and written about the decline of management science education in MBA programs. The results of a recent INFORMS survey of professors who teach OR/MS in business schools indicate that "only 13 percent felt the role [of management science] is greater now than five years ago. Looking five years ahead only 21 percent expect the role to be greater five years in the future" [INFORMS 1997]. Amid all of the doom and gloom that accompanies such statements, we are missing an important point. Management science is more important to business education than ever, and management science can be implemented by MBA students more easily than ever. What we require is a radical change in the way we conduct the first MBA course in management science.

A number of alternatives have been suggested to reverse this trend. The most notable are to shift from intelligent consumer to active modeler [Powell 1997a], to use spreadsheets as the primary modeling vehicle [Savage 1997], to teach management science using cases [Bodily 1996], and to teach quantitative analysis with a focus on managerial relevance [Carraway and Clyman 1997]. All of these recommendations have merit and can improve the quality of management science education. They also relate to the position taken by the INFORMS Business School Education Task Force [1997, p. 36]:

> We recommend that individual faculty embed their analytical material strongly in a business context, use spreadsheets as a delivery vehicle for OR/MS algorithms, stress the development of general modeling skills, and work toward effective collaboration with colleagues in the functional areas of business.

Another successful approach that meets

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the spirit of the task force recommendations has evolved in the part-time MBA program at Villanova University over the past five years. This approach includes the following actions:

(1) Empower students to identify, model, and solve practical business problems themselves. This relates to and perhaps expands upon the shift in paradigm to active modeler from intelligent consumer that Powell [1997a] discusses.

(2) In the management science course, offer a set of integrated modules, rather than a survey that delivers a "technique of the week."

(3) Present management science methods and full-feature modeling software together as one integrated learning system.

(4) Enable student groups to conduct projects in which they apply computer-based management-science modeling to practical problems that their organizations face.

(5) Develop students' presentation and communication skills to enhance the likelihood that their management science projects will be implemented.

(6) Remember that management science is an exciting discipline because it helps solve important business problems, and for this reason use a dynamic and enthusiastic presentation style.

As recently as five years ago, we told students that our goal was to help them become intelligent consumers of management science. We wanted them to learn enough about the theory and applications of management science so that they would know when to initiate a study, when to consult a specialist, and how to review the specialist's work. While this goal is still important, we have instituted changes that enable us to state during the first class that we want every student to complete one successful management-science implementation within a year of completing the course. Many students do this during the semester through one of their projects. Shifting the focus from what students could or would do with management science to what they can and will do dramatically improves the image of our course. In general, the faculty views the course favorably and sees it as practical and useful. Students tell us that our course is now one of the most practical and useful courses in the MBA program. Perhaps even more important than what our students are saying is what our students' employers are saying about the course:

> I understand the work and personal sacrifices part-time students go through when pursuing a part-time MBA, and it is encouraging to see students' academic pursuits have an immediate impact on their productivity and contribution at work.

> It became clear very quickly that the course work and resources offered to MBA students at Villanova, and specifically within this class, are not only thorough but applicable to today's business environment.

> It is projects like this one that make her time and effort away from the office as well as our tuition-reimbursement investment worthwhile and beneficial for Kristen, [company name], and myself.

> I personally appreciate the efforts put forth as a result of this class and feel [company name] has made a beneficial investment.

> I appreciate this project and effort and am pleased to see that Marty's MBA is paying off sooner rather than later.

The MBA Program

The MBA program at Villanova University is one of many part-time MBA programs that primarily serve students in the highly competitive Philadelphia metropolitan region. Currently, of the approximately 650 active students in the program, about 10 percent are classified as full-time students (registered for nine or more credit hours per term). Some of the major feeder organizations to our program are Vanguard, Arco, Ford, Lockheed/Martin, Wyeth Laboratories, and Boeing. However, each of these employers sends only two to five students each term. Table 1 shows some of the characteristics of those students accepted during the past two academic years.

The MBA curriculum was recently revised and is now organized into six basic core courses, two required advanced core courses, six additional advanced core courses (of which the student must select five), and four elective courses. Depending on the student's educational background, the basic core courses can be waived. Our course is one of the six advanced core courses and its title is "Decision technology for business application (DT)." The course title reflects our focus on decision making and the use of computer technology to support management-science modeling and problem-solving activities. Related course work in the basic core includes "Quantitative and operations analysis." This course provides basic knowledge of descriptive and inferential statistics but does not cover mathematical programming, simulation, or decision analysis. Our MBA program does not require students to own a personal computer, but students must possess basic computer skills (word processing, databases, and spreadsheets) upon matriculation. As is typical of most part-time MBA programs, the use of information technology is increasing. For example, in various courses, students make PowerPoint presentations, use Excel, access the Internet, and use financial databases. The college has several computer classrooms connected to a local area network (LAN), and it has two computer laboratories connected to another LAN for student access outside of class.

Course Overview

The DT course meets once a week for two hours and 45 minutes in a computer classroom. The computer classroom contains an instructor's PC and 20 student PCs all connected to the classroom LAN. At Villanova, MBA classes average 27 students, and typical DT classes range from

	Fall 1997	Spring 1998	Fall 1998	Spring 1999
Number of accepted students	188	69	161	71
Average years of experience	5.0	5.2	5.0	6.4
Average GMAT	586	576	589	588
Range GMAT (middle 80 percent)	520–640	490–660	510–670	530–650
Average GPA	3.10	3.11	3.20	3.10
Range GPA (middle 80 percent)	2.77–3.52	2.50–3.82	2.59–3.73	2.59–3.73
Percentage men/women	65/35	61/39	70/30	69/31
Percentage undergraduate business majors	57	51	63	44
Percentage undergraduate engineering majors	22	12	15	20

Table 1: The summary student profile data for the past two academic years show that the profile of Villanova's MBA students is fairly typical of most part-time MBA programs.

24 to 33 students, thus requiring some students to share a computer. Table 2 lists the topics for the 15 class sessions.

The DT course comprises three modules: mathematical programming, simulation, and decision analysis. Each module addresses the theoretical underpinnings of the models covered. We emphasize understanding key concepts rather than the details of specific algorithms. In each module, students use one or more modeling software packages to model various business problems. These packages are LINGO [LINDO Systems, Inc. 1998] for mathematical programming; Extend [Imagine That, Inc. 1998], and Stat::Fit [Geer Mountain Software Corporation 1998] for simulation; Expert Choice [Expert Choice, Inc. 1998] for decision analysis; and, to a lesser extent, Excel as an interface with LINGO and Extend for data input and model output.

We have prepared an extensive set of PowerPoint presentation notes for each module, and these are accessible to the students on the classroom LAN. During class, students have access to connected computers. The instructor and students toggle between PowerPoint and any modeling software needed. Beginning with the fall 1997 semester, students purchase a custom-published course pack containing (1) a book of the PowerPoint slides and portions of three software manuals and (2) a CD containing student versions of LINGO, Extend, and Expert Choice, as well as sets of model files that we developed for each module. We are in the process of writing a textbook for the course. Beginning with the spring 1998 semester we have experimented with web-based software to support communication and collaboration among faculty and students and to deliver course materials and files over the web.

Comparing spreadsheets with modeling software

Recently some management science educators have begun using spreadsheets as the primary modeling vehicle for teaching management science. Savage [1997, p. 43] has discussed the pros and cons of using spreadsheets for modeling. He stated that a compelling reason for using spreadsheets is the fact that there are "thirty million users" and that "spreadsheets have overwhelmingly become the analytical vernacular." 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 Savage's INSIGHT.xla [1998]. These products facilitate the application of management science. Savage [1997] also discusses the importance of using objects rather than algebra to teach OR/MS applications. An object can be a small spreadsheet model that a user can scale up within limits and enter data to solve real problems. For example, a transportation decision object is 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.

Savage [1997; 1998] also discusses some of the disadvantages of spreadsheets, particularly their limitations relating to documentability, scalability, and hyperscalability. Documentability is the ability to

Session	Class topic
1	Introduction and solution of linear, integer, and nonlinear programming models
2	Sensitivity analysis and mathematical programming formulations using LINGO—part 1
3	Mathematical programming formulations using LINGO—part 2
4	Mathematical programming formulations using LINGO—part 3
5	Mathematical programming formulations using LINGO—part 4
6	First examination
7	Introduction to simulation with Excel and simulation modeling using Extend—part 1
8	First project due; simulation modeling using Extend—part 2
9	Simulation modeling using Extend—part 3
10	Simulation modeling using Extend—part 4
11	Introduction to decision analysis and AHP using Expert Choice—part 1
12	AHP using Expert Choice–part 2
13	Project preparation and preliminary review
14	Second examination
15	Presentations of second group projects

Table 2: The class schedule for "Decision technology for business application" includes three key modules: mathematical programming, simulation, and decision analysis. This course also contains two exams and two sessions devoted to project preparation and presentation.

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, for example, adding a time dimension to a static production-planning model.

In the opinion of Savage [1997; 1998] and many others, the benefits of spreadsheets outweigh their disadvantages. We agree that the use of spreadsheets is clearly a step in the right direction toward the integration of computing technology into management-science modeling and application. In the past, we have experimented with the use of spreadsheets and have encountered scalability and hyperscalability problems. For example, several years ago we used spreadsheets to illustrate the basics of analytical hierarchy process (AHP) computations. However, we found that it was difficult to address several important modeling issues: developing multilevel hierarchies of arbitrary size (scalability and hyperscalability problems); performing dynamic graphics-based sensitivity analysis; and identifying the most inconsistent judgments. For these reasons, we adopted Expert Choice.

Our experiences with spreadsheet-based optimization are similar. We encountered scalability and hyperscalability problems and decided to use the LINGO modeling language instead. An added benefit of LINGO is that it allows the user to express sets of constraints in a single compact statement.

In the area of simulation, we experimented with spreadsheets and their add-ins. We found that it was difficult for students to address the queuing and process-redesign situations that often occur in practice. For example, in considering the application of simulation for modeling a supermarket, the discussion inevitably turns to such behaviors as customers balking and reneging and the changing patterns of customer arrivals and number of available servers during the day. Currently available spreadsheet add-ins are unable to address these issues. One could argue that additional add-ins are needed and perhaps could be developed. However, we want to empower our students to model these and other behaviors that interest them. Visual simulation software packages, such as Extend, do this.

Savage [1997, p. 44] succinctly addressed these spreadsheet limitations:

> [T]he spreadsheet will eventually be brought to its knees as the complexity of the model increases. Thus, the initial goal of the worksheet should be to convince management of the validity of the approach, so they will fund a more robust model.

We believe that it is now possible to avoid the middle step of using spreadsheets and move directly to more powerful modeling software, such as LINGO, Extend, and Expert Choice. An important issue for many management-science educators is whether MBA students have the skills they need to take advantage of modeling software. Modeling software was originally developed by management and computer scientists primarily for use by management scientists. These developers were not very concerned with its ease of use or the time and effort a new user would expend to learn how to construct models. Recently, software developers have become much more attentive to these issues. In addition, today's MBA students have the skills needed to effectively navigate modeling software within a Windows environment. Both of these developments support the transition to the use of modeling software in the classroom. Powell [1997b, p. 10] alludes to these issues when he states that

> there is no doubt that all software is gradually becoming easier to use, and students are gradually becoming more skilled in using computers. As this occurs, perhaps we will find less reliance on spreadsheets in teaching management science and use of more specialized and powerful tools. This is only one of many open issues in the teaching community at this time.

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. What is needed then is a pedagogical approach that enables students to learn the essentials of modeling with the software so that they can create their own models.

The building block approach

The approach we have taken is to present software and modeling together. This is similar to Savage's idea [1997, p. 44] of teaching students "how to assemble applications from decision objects, building block style." We have streamlined the initial learning process by using materials that help students understand the operation of the key software blocks and their relationship to modeling activities. After we cover the first indepth example in each module, the student quickly moves along the learning curve. He or she is then able to model more realistic situations, first in homework exercises, then on exams, and lastly in the projects. Students develop modeling skills because we emphasize how the various examples contain blocks that they can combine or modify to address other problems. The key is to help students to formulate and think about modeling within the context of the software. When they learn how to model a variety of problems using the software, they find that (1) many problems their companies face are simply variations of these models, and (2) in some instances, they can extend these modeling blocks to other application areas.

Mathematical programming

We begin the mathematical-programming module by discussing the solution of linear, integer, and nonlinear-mathematical-programming problems using the graphical-solution method. We do not focus on the details of the calculations but try to provide students with the basic ideas behind the solution procedures. We also show how the same problems can be solved in the algebraic mode of LINGO. We assign homework problems that will increase the student's familiarity with LINGO.

We want every student to complete one successful MS implementation.

We begin the second class by covering the ideas underlying sensitivity analysis and the interpretation of LINGO outputs. We use a series of hands-on exercises with LEGOs, based on an article by Pendegraft [1997], to illustrate key sensitivity concepts, including slack and surplus, dual price, reduced cost, and range analysis. Homework problems explore a range of sensitivity-analysis concepts. LINGO model files for these problems are provided. Taken together the material covered thus far provides students with a solid foundation for understanding and interpreting mathematical-programming problems.

During the second half of the second class and the next three classes, we cover modeling mathematical-programming applications using the LINGO modeling language. We address application and computer modeling as a unified topic. Students learn how to model mathematical-programming problems using LINGO's pseudocode, which is similar in some respects to a programming language. A major advantage of the LINGO modeling language is that it allows users to express a series of similar constraints in a single compact statement. These statements can be thought of as building blocks that enable the student to model increasingly complex and realistic problems. As a result, the LINGO modeling language plays a pivotal role in developing a student's modeling ability.

We use a diet problem as the fundamental example of applying the LINGO modeling language. We have found that using a very simple initial model works best when trying to explain the most important LINGO modeling concepts. Once students grasp the basics of LINGO modeling, they are able to set up model variations of the diet problem, for example, by adding menu items and nutritional requirements and specifying bounds on the decision variables.

Next we consider a family of applications based on the transportation problem. We begin with the basic transportation problem with a single distributional link, such as shipment of product from warehouses to customers. We extend this model to problems with unbalanced supply and demand, to problems eliminating shipping over specific routes, to a fixed-charge problem, to a multimodal transportation problem. In addition, we demonstrate how students can use an Excel interface with LINGO for data input and output.

Students made recommendations on ways to improve the LINGO language.

During the next class, we continue with additional LINGO modeling applications. We begin with an employee-scheduling problem using a covering approach. Next, we present the basic ideas and modeling approach underlying the Markowitz financial-portfolio problem. We cover the concept of the efficient frontier and use the capabilities of LINGO to construct the covariance matrix based on investment-return data. The resulting quadratic-programming problem can be easily modified for varying types of investments and available return data.

We cover the traveling salesperson problem (TSP) during the fifth and final mathematical-programming class. We begin by showing how the transportation problem previously developed can be transformed into an assignment problem. We explain how applying the assignment-problem formulation to the TSP can result in subtours. We then present LINGO-based TSP and vehicle-routing heuristics. Other applications presented include capital budgeting with multiple-choice and conditional constraints, multiperiod production scheduling, and nonlinear retail-space-allocation planning. We develop all of the models in the LINGO modeling language and make them available on the LAN and the CD.

The homework assignment after the first LINGO-modeling-language class reinforces basic modeling concepts. The assignments after the last two mathematical-programming classes focus on applying the LINGO modeling language to new applications. We encourage the students to apply and modify blocks of LINGO code from earlier models. This reinforces the idea that many new applications can be based on extensions and modifications of blocks from existing models.

Simulation

We begin the second module by presenting the theory of Monte Carlo simulation, starting with random numbers and games of chance, then moving to pseudo-random-number generation and business applications. Several examples illustrate simulation in Excel using =VLOOKUP and other built-in functions. We conclude the first class with an overview of how Extend is used to build a multiserver queuing-simulation model. The building block approach to decision modeling applies directly in Extend, since the user constructs simulation models using entities called blocks (Figure 1).

Each of Extend's blocks specifies an action or process. Information comes into a block and is processed by the program in

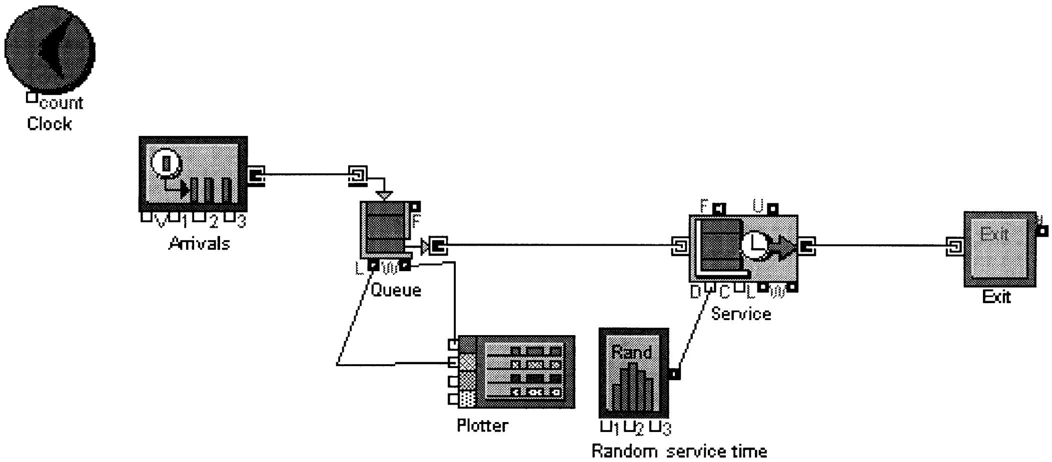

Figure 1: Creating a multiserver queuing model in Extend requires linking Extend blocks that generate random arrivals, put items in a queue, generate random service times, and remove items after service is completed. A plotter displays key queuing outputs over time, such as line length (*L*) and waiting time (*W*). The block in the upper left-hand corner tracks time during the simulation.

the block. (The programming language is transparent; students simply retrieve blocks stored in libraries.) A given block then transmits information to the next block in the simulation. These blocks are connected together to form a model. Blocks are used to generate arrivals, place arrivals in a queue, provide service, and exit. Additional blocks create the clock, provide random service times, and plot the queue length and queue waiting time. During the next three classes, we introduce additional blocks and modeling features of Extend and develop simulation theory and applications. Like the mathematical-programming module, Extend plays a pivotal role in developing a student's modeling ability.

During the second simulation class, we explain in great detail the standard multiservice queue introduced during the previous week. In essence, we use the same pedagogical approach we used with the diet problem in the mathematical-programming module. We also look at two important queuing relationships: (1) $\lambda < k(\mu)$, and (2) $L = \lambda W$ [Little 1961]. We discuss why the exponential and Erlang distributions are often used to describe interarrival-time and service-time data, respectively. We also demonstrate how to use a software package called Stat::Fit to test the fit of empirical data to most well-known probability distributions. Stat::Fit can rank the fit of a broad range of distributions using goodness-of-fit tests. (See Benneyan [1998] for a favorable review of Stat::Fit.) We end the class by running and analyzing the multiserver model.

In the third class, we focus on building a number of variations of the multiserver model, discussing additional Extend blocks. These model variations include reneging, balking, changing average interarrival time during the simulation, and changing the number of servers during the simulation. We conclude by discussing why multiple simulation runs are needed. We illustrate the impact of multiple runs by computing confidence intervals for key simulation output statistics, such as average and maximum queue length and average and maximum waiting time. Students learn that using point estimates in decision making can be misleading if confidence intervals are very wide relative to the size of the point estimate. Also students learn that for a 95-percent confidence interval, there is a 95-percent probability that the true value of the population statistic is within this interval, and as a result they must consider how values within this range affect their decisions.

In the last class in the simulation module, we address additional models and uses of the simulated results. The additional models include multiqueue simulations and a continuous-time financial simulation. We use the latter example to illustrate the difference between discrete and continuous-time simulation. As part of this discussion, we show how Extend can easily address the issue of cold starts. Next we consider a sequence of examples to show how to use simulation in process redesign. We also consider the trade-off between cost and service-level issues.

The first homework assignment is designed to reinforce simulation concepts and the basic features of Extend modeling. The assignments after the remaining three classes concern applying Extend to new applications. We encourage the students to apply and modify the Extend models developed in class.

Decision analysis

We begin the third module by describing the important concepts of classical decision analysis, including utility theory. We discuss the characteristics and calibration of multiattribute utility models and offer the analytic hierarchy process as an alternative. We present the theory behind the AHP, emphasizing the use of pairwise comparison judgments and how they result in a ratio scale of measurement. We discuss in depth the concept and implications of inconsistent judgments. We conclude the first class with a detailed discussion of the motivating example for this module, how to use AHP to decide which car to buy. We illustrate a simple computational approach that provides good estimates of the final weights of the decision alternatives. We then briefly illustrate how to solve the same problem using Expert Choice.

In the second class, we consider in more detail the process of modeling using Expert Choice. Specific topics include rank reversal and the choice of either the distributive or ideal modes of synthesis, measurement of inconsistency, structuring multilevel hierarchies, developing AHP rating models, individual and group decision making, and various sensitivity-analysis formats. During this class, we present a series of new AHP models. Application areas include prioritizing alternatives and planning resources in selecting products and projects, evaluating employees, selecting technology, locating facilities, choosing vendors, and deciding on transport modes and carriers. The homework reinforces the process of building Expert Choice models using pairwise comparisons and ratings data.

Examinations

The first in-class examination covers mathematical programming. The students can use notes, supporting materials, and a computer with LINGO during the exam. It includes questions on sensitivity analysis using LINGO output and questions on applying LINGO modeling concepts.

The second exam has the same format. It covers AHP and simulation and the supporting software packages and includes questions on formulating models and interpreting computer output.

Projects

The students form project teams of two to four members and complete two projects during the semester. The goal of the first project is to apply mathematical programming to a problem one of their employers faces. In the second, they use simulation or the AHP or both. Prior to the full-scale inclusion of Extend about two years ago, approximately 90 percent of the second projects used AHP, with a few using spreadsheet-based simulation. Now the projects are almost evenly split between AHP and simulation, with a few groups using AHP in combination with mathematical programming or simulation. In some cases, students conduct a pilot study using real company data. In others, they completely model the actual situation. Our experience has shown that good project topics can be found in nearly all organizations. We were pleasantly surprised to find that this statement applies not only to AHP and simulation projects, but also to mathematical-programming projects.

The completed projects are extremely important outcomes of this course. We try to provide the students with the knowledge, skills, and tools they need to successfully complete the projects. We serve as facilitators to the teams as needed. In general, our assistance is limited to clarifying the goals of potential project ideas and infrequently providing some modeling support. Generally, once the students on a team start thinking about a topic for their project, one will identify an important problem his or her organization faces that can serve as a project topic. Frequently, the problem is directly related to the student's area of responsibility at work. This connection motivates the student to mobilize the team to complete and implement the project.

The proof of the pudding is in the application.

It is difficult to know what percentage of the projects are successful. We consider a project successfully implemented if it causes a positive change in the business or if it demonstrates to managers the relevance of using OR/MS in the business. Projects seem to fall into four categories that can be assessed by the end of the semester: implemented immediately (about 25 percent); a very good chance of being implemented in the near future (about 25 percent); a chance of being implemented (about 25 percent); and very little chance of being implemented (about 25 percent). Generally all but the last category have been reviewed to some degree by managers in the companies sponsoring the projects. The emphasis we place on projects and applications clearly contributes to the favorable results observed. However, we believe that many of the projects would not have been attempted or would not have enjoyed the same degree of success without the availability of modeling software. Armed with an arsenal of sample models that can be easily modified or expanded, students can immediately apply management science in their work environments.

We grade the written project reports based on the quality of the modeling and the extent to which the team moved toward implementation of its results. We use an evaluation form in determining the report grade. The evaluation form has instructor ratings of seven items including problem formulation, model representation, results, implementation, creativity, writing, and organization. We used the AHP in developing this form.

We require students to post an executive summary of their first project in our web software. We also require each group to present its model and results of the second project in class. These activities help students learn to effectively communicate the benefits and results of their projects to management. We grade the in-class presentation based equally on content and communication criteria using an evaluation form that we developed using the AHP. The evaluation form has ratings of six items including creativity, model formulation, model results, organization, communication, and presentation pace. We ask the members of the audience to fill out the same evaluation form. We record the median student grade and average it with the instructor's grade to obtain the project-presentation grade. We return all evaluation forms to the project teams to provide constructive feedback.

During the last two years, typical math-programming projects 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 its results were within two percent of a forecast generated by an in-house soft-

ware 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 the bank's proprietary portfolio software. Another group developed a two-phase model in which it 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. The members 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 new 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 students'] 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.

Typical simulation-based second projects over the past two years have focused on various queuing 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.
(1) One group developed an Extend simulation model to analyze the multistage test procedures for a critical and central component used in launching all digital CATV systems. The four key components simulated are the test procedures for software load, final unit level test, burn-in station, and rework station if the item fails at any previous stage. Given a demand forecast, the group used simulation to determine if there were enough stations at each of the four stages. The group recommended changing from one to two final-test stations, from 30 to 35 burn-in slots, and keeping the proposed one software-load

station and the one rework station. These results were presented to corporate personnel and implemented.

(2) Several groups have studied call-center operations, including the operations of a service bureau for customer support; telephone answering for a large medical practice; an auto-attended phone system for a large insurance company; and help-desk telephone support. For example, one group used simulation to determine the number of servers needed to staff an online technical assistance hot line for a major investment firm. Its model allowed customers to renege and average interarrival times to vary during the day. The students gathered interarrival data for 22 half-hour periods throughout the day for 19 days, as well as service time and renege data. They analyzed the data using Stat::Fit. Although customers were experiencing long delays in reality, the simulation confirmed that the firm was using the appropriate number of servers, given its targets for average waiting time and reneging. However, the comparison between the actual results and the simulation results suggested that the available servers might not always be taking calls. Further investigation confirmed that the servers were spending too much time performing nontelephone-support activities. The students recommended ways to correct the problem to managers who said they would consider adjusting the servers' work responsibilities.

(3) Another group used simulation to analyze whether a company should open an additional cash-register station as part of the standard design for its new high-volume fast-food outlets. Currently this chain, one of the largest in the country, supports only a fixed number of registers in a prototypical store configuration. Coupling the simulation results with an analysis of revenue and operating costs, the group demonstrated that adding a cash register would be profitable. The group presented its recommendations to management.

(4) Reengineering a processing system for medical insurance claims was the topic for another group's second project. The students used simulation to analyze the performance of the proposed design. Internal consultants independently studied the same problem, arrived at essentially the same results, and drew the same conclusions as the group. In their presentations to management, the students explained that simulation can be used to verify approaches to work-flow problems.

(5) Two other groups analyzed the effects of technological change using simulation. The first studied the impact of automatic vehicle information (AVI) systems for use in collecting tolls. AVI systems can process transactions for cars traveling at speeds up to 55 miles per hour, whereas manual-attended lane speeds average 2.5 miles per hour. The group considered the performance of different tollbooth-plaza configurations, including attended, automatic, AVI systems, and combinations of all three. The students collected interarrival-time and service data from one Pennsylvania turnpike interchange and obtained operating-cost data from the Transportation Research Board. Based on their analysis, the students recommended a configuration to the Pennsylvania Turnpike Commission.

A second group analyzed a new bank-security system, which is designed to stop a group of people from taking control of a bank. Essentially, a customer would enter the first door of a bank, which locks before the second door is opened. A metal detector, similar to those used in airports, is used to scan the customer. If too much metal is detected, the second door remains locked, thus trapping the customer. Otherwise, the second door opens and the customer enters the bank. The security system allows the bank to set the sensitivity of the metal detector. If it is too sensitive, many "innocent" customers would be trapped between the doors. If it is not sensitive enough, the bank could be seized. The student group wanted to investigate the impact of the sensitivity settings on the security system to determine how many customers would be locked between the doors. After multiple model runs, the students presented their results to management, including a recommended sensitivity setting.

Typical AHP-based second projects over the past two years 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 and D) resources to competing projects. (Some of these projects are based on the ideas of Liberatore [1987].) One of these projects is currently under consideration by a large pharmaceutical company. Another group

project led to further work by one of the group members who successfully implemented an R and D resource-allocation method after completing an independent study. This effort also resulted in two publications [Ross and Nydick 1992 and 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 its 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.

Letters received from company representatives often comment on the value of projects completed in their organizations. A few examples follow.

Even if an approximation, the potential savings outlined in the group's paper of $30,000 per year are impressive. I found the results generated from this model to be a very implementable solution.

You never cease to amaze me. If the team agrees, we start planning out the next quarter accordingly using the tool. Best case, we do 200% of goal and you get a big bonus and another trip to Hawaii. Worst case, we make adjustments as necessary to the plan, nothing lost (at least we actually tried something scientific instead of Tom's dart-board approach). . . .PS—Remind me of this proposal next time you need to bail on a sales call because of an MBA class.

The group has offered us a solution to a problem that has cost [company name] countless amounts of time and money. In a trial run the auditor scheduling time was reduced from eight hours to two. In addition, each auditor's efficiency was improved noticeably. Travel times were reduced and the number of units audited in one month increased nearly 10 percent. We hope to present the benefits to our home office in [city name] for company-wide approval. I am confident that upper management will be equally impressed.

I have more faith in this method than our traditional spreadsheet models or personal decision making. These results brought up scenarios that we would have never considered before. At the very least this shows that more time needs to be devoted to reviewing conclusions that were made years ago and are taken for granted now as being correct.

After reviewing the programming logic for the cup molding process controllers we noted that they were, as you stated, directing raw materials to a primary cup molder in the event of an equal length molding queue. I have instructed the engineers in the plant to reprogram the process controllers to emulate a random material allocation in the event of equal raw material storage in the cup molding staging area. I look forward to seeing you the week of January 18th to review the possibility of simulating the [name omitted] facility.

After what I expect to be a successful launch and implementation of this model, I will propose to the director of the HR that the entire US division of the company utilize the model for 1999 evaluations. In addition, I will propose that the European, Middle-Eastern, African, and Asian regions of [company name] utilize the model with cultural considerations made.

Concluding Remarks

In our first MBA course in management science, we integrate management-science concepts and modeling software for immediate application in the students' working environments. In our opinion, the proof of the pudding is in the application. Our approach has empowered part-time MBA students to produce and often implement high-quality management-science-application projects. Students learn to appreciate the value of management science as an applied discipline. We plan to improve this course, while steadfastly emphasizing student practice.

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