**An Internet Resource for
Operations Research Models, Methods and Applications
by Paul A. Jensen**

Students and practitioners are often discouraged from using quantitative analysis techniques because of the diffuse nature of informational and computational resources. A person with a problem to solve may have some idea that quantitative analysis might be useful, but finding a simple resource that explains the variety of models and methods available might be a challenge. A search of the Internet on specific terms or phrases returns a plethora of references. Some might be helpful, but others are theoretical and confusing. I recently had an e-mail exchange with an analyst who was convinced that integer programming was the way to solve her problem, and she was trying to learn enough to solve a real problem. Clearly, she was having a difficult time learning on her own, so I asked what resources she was using. Her collection consisted entirely of graduate level integer programming textbooks. Any one of them would be a challenge, even if used with the help of a professor in a formal class.

My goal in creating the web site *Operations Research Models and Methods* (ORMM) was to provide an internet resource that provided clear descriptions of the major model categories considered in an introductory Operations Research (OR) textbook. Then an isolated student or practitioner could review the collection of topics to see where his or her problem fit among the pantheon of model types. Further, for each model type the site was to provide an add-in for Microsoft Excel that implemented an OR method to solve an instance. Since its introduction in 1999 (Jensen 1999), the ORMM site has grown to include twelve articles on the basic OR models for optimization, stochastic processes and probability analysis, student problems for each model type, descriptions of the traditional mathematical programming methods for motivation, a collection of seven articles on applications typically considered in operations management and industrial engineering, 36 Excel computational tools programmed with Microsoft Visual Basic for Applications (VBA), demonstration Excel workbooks for all the add-ins, and instructional materials for several courses. This document describes the ORMM web site as it stands in June 2007.

The ORMM[1] web site holds a large collection of materials for the study of operations research (OR). Figure 1 shows the front page of the web site. Links from this page navigate to the several main sections of the site. The materials are organized under the general headings of models, methods, computation, problems and OM/IE. The *models* section contains articles describing how decision problems can be expressed in a form amenable to analysis by operations research. The *methods* section contains articles that explain the theoretical development of solution methods for mathematical programming. The *computation* section provides instructions for Microsoft Excel add-ins that can be used to solve models. The *problems* section provides opportunities for student practice. The *OM/IE* section addresses applications typically considered for operations management and industrial engineering. Other pages on the site provide download access to the add-ins and example Excel workbooks. A tours section organizes the site by

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[1] Underlined words or phrases are liks to www pages.

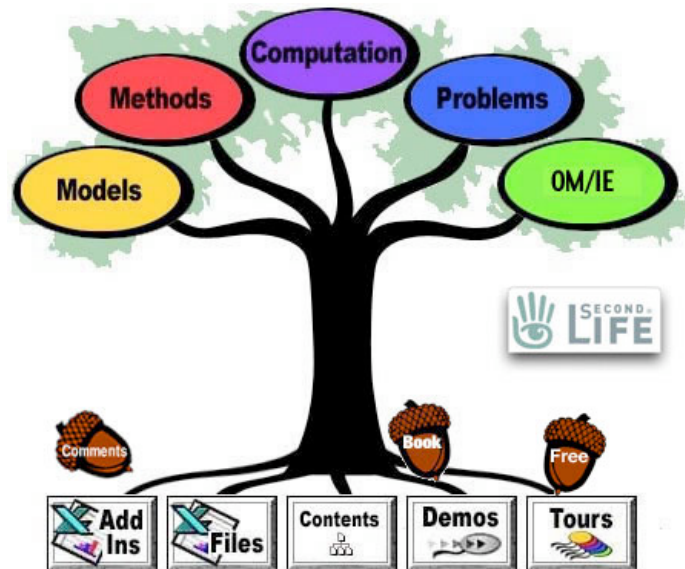specific topics. An <u>instruction</u> section provides links to materials on the site for teaching several courses.

Figure 1. The ORMM Front Page

Purpose of the Site

Students
Most students will enjoy the OR Models section. Here are surveys of most of the topic areas that would be covered in an Introduction to Operations Research course, as well as more advanced courses. In the Methods section students will find introductions to the traditional mathematical programming methods. The teaching add-ins operate in either demonstration mode for illustration or instruction mode for practice. In the Add-ins section and the associated Computation section students will find computational methods that can be applied to most numerical textbook problems. The Problems section provides practice problems, some with answers. Students interested in Operations Management or Industrial Engineering will find in the OM/IE section discussions and add-ins appropriate for a number of problems that arise in these fields.

Teachers
Although the site was written to support the authors' book, *Operations Research Models and Methods*, it will be useful for almost any introductory textbook. The site does not provide complete mathematical background to the topics considered. Teachers will find many resources to support teaching. The Instruction section provides resources for several courses including PowerPoint presentations. One of the main benefits of using add-ins for the teacher is the ability to create examples and homework problems that are more interesting than the usual textbook problems. Several of the algorithmic add-ins provide outputs that help explain the processes used to solve problems.

Practitioners
The add-ins will be particularly interesting to persons practicing Operations Research. Many times it is useful to test concepts on small problems before extensive programming or the

purchase of off-the-shelf software. The add-ins cover a great variety of problems and they are very easy to use. The VBA code is easily accessible, so practitioners can modify the add-ins or create new ones. The code can be viewed using the VBA window of Excel. It is password protected, but the password is given on the ORMM site.

Models Section

The models section provides descriptions of the various types of models used by operations research analysts. The division is based on the mathematical form of the model. All the models described here are solved with Excel add-ins.

The list below shows the topics considered. Most of the topic areas include pages with a general description, terminology, and examples. The descriptions are easy to read, but they do not replace an introductory textbook.

ORMM: Models
What is OR?
Linear Programming
Network Flow Programming
Integer Programming
Nonlinear Programming
Dynamic Programming
Combinatorial Optimization
Stochastic Processes
Discrete Time Markov Chains
Continuous Time Markov Chains
Simulation

Methods Section

This section presents resources to help teach/learn mathematical programming algorithms. A variety of media are used in the presentation, but the teaching add-ins are central. The six Teach OR Excel add-ins describe the traditional math programming methods. The Teach Operations Research dialog, shown in Figure 2, loads and unloads the add-ins in Excel.

Appendix A has a brief discussion of each add-in. The add-ins allow user interaction to guide the solution processes.
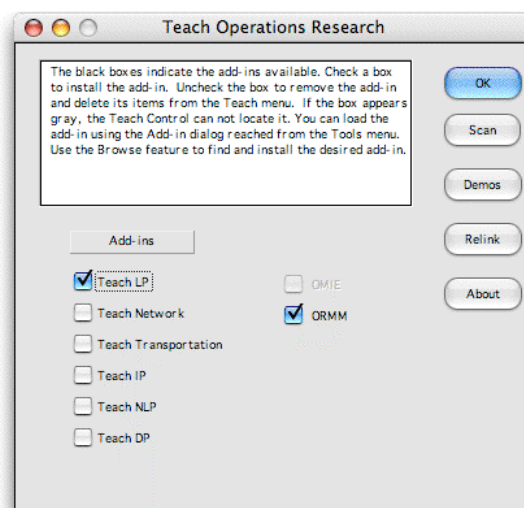
Figure 2. Teach Operations Research Collection

When an add-in is installed, the *Teach* menu appears in the menu bar of Excel. The add-in provides a list of commands that create and control problems. Figure 3 shows the commands with the <u>Teach LP add-in</u> installed.
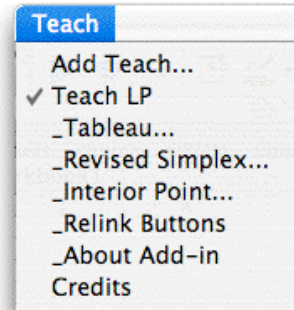
Figure 4 shows a sample problem as it is being solved with the Tableau method. The student determines the variables to enter and leave the basis. The computer performs the pivot operation.
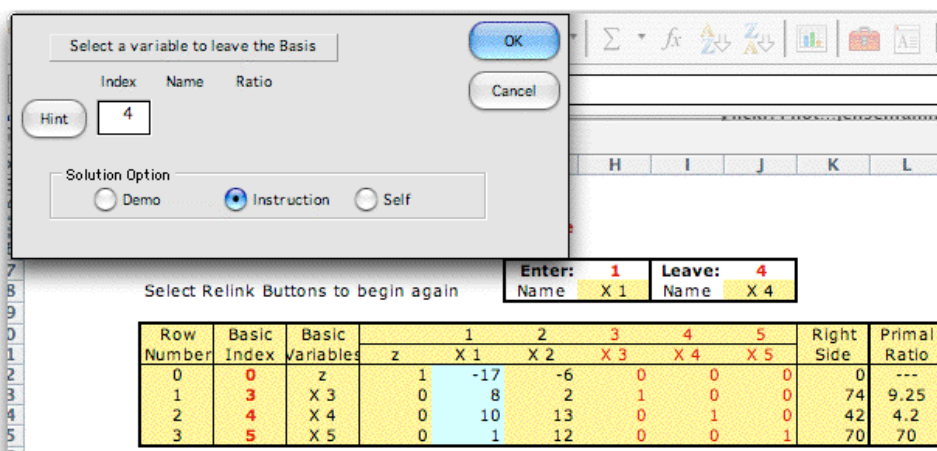

Figure 3. The ORMM Menu

Figure 4. An iteration of the Teach LP add-in for the Tableau method.

Figure 5 shows a tableau constructed by the <u>Teach Transportation add-in</u> on an Excel worksheet. The student chooses the sequence of cells to enter and leave the basis.
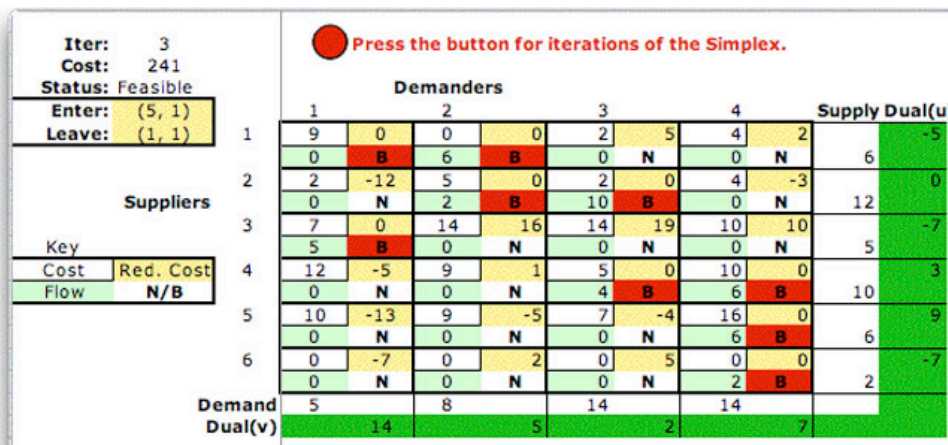

Figure 5. A tableau from the Teach Transportation add-in

Computation Section

This section has instructions for an extensive collection of Excel add-ins that implement a variety of the analytical procedures from operations research ranging from mathematical programming to stochastic processes. The add-ins make complicated procedures immediately and easily available so that users can focus on data and modeling rather than formulas and algorithms. The programs are coded with VBA with Excel providing the interface. There are several advantages to this approach including broad familiarity with spreadsheet operations, the availability of a variety of methods in a single package, the possibility of using two or more methods simultaneously and the opportunity to perform data and decision analyses in the same workbook. The student or practitioner can formulate and solve meaningful problems without the expense of stand-alone programs and sophisticated workstations.

The *Add ORMM Add-in* loads and unloads members of the collection. The dialog from that add-in is shown in Figure 6. Add-ins are installed by checking the associated boxes.

The collection of add-ins is shown by the titles on Figure 6. The add-ins are described in Appendix A.
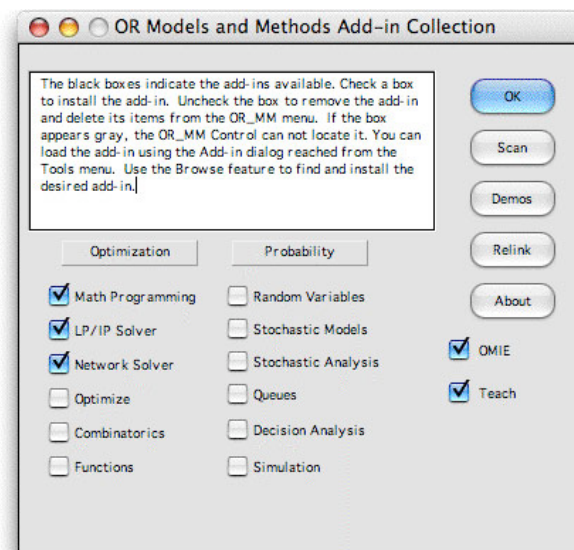

Figure 6. The OR Models and Methods Add-in Collection

Once an add-in is installed, new menu items are placed on the Excel menu. Figure 7 shows the ORMM Menu with the Math Programming, LP/IP Solver, and the Network Solver add-ins installed.

Every add-in has a similar menu. Clicking an item on the menu causes a program to run that builds a model or performs some action on an existing model. Model construction is typically directed by a dialog where the user enters model parameters.
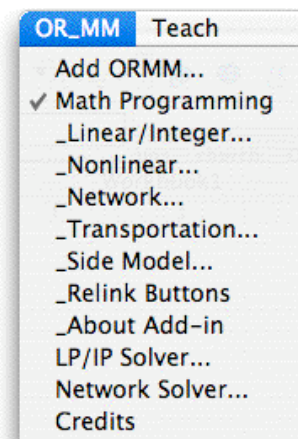

Figure 7. The ORMM Menu

Figure 8 shows a small linear programming model created with the Linear/Integer command. Models are limited in size only by the size of the spreadsheet, although large models may be impossible to solve.
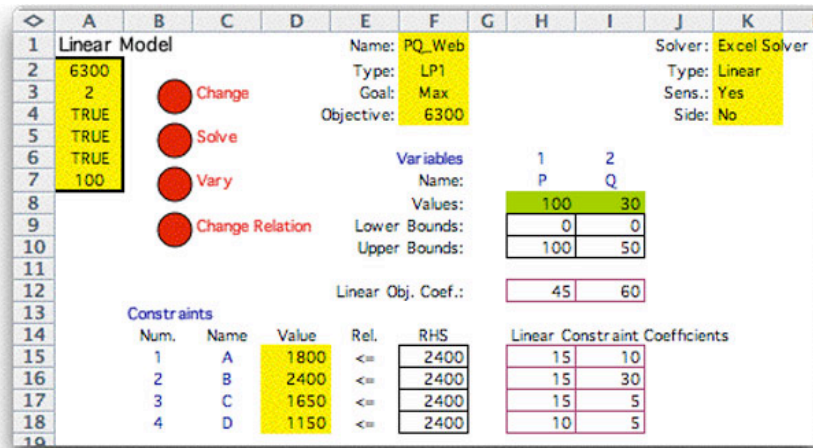

Figure 8. A small LP model created by the add-in

Figure 8 illustrates several design features that are used throughout the collection. The red buttons provide access to programs that perform some action on the model. The *Change* button adds or deletes rows and columns to the model, changes the integer requirements, or changes the Solver designation. The *Solve* button initiates the solution algorithm; the *Vary* button provides a parametric analysis, and the *Change Relation* button helps change the constraint relations. Yellow fields indicate cells that the user should not change, white cells hold user data and green cells hold the results of algorithmic computations. The yellow cells in column D have Excel formulas that compute the amount of each resource used by the solution. The objective is computed in cell F4. These numbers automatically update as the user varies the solution value in the green cells of row 8.

When the Solve button is clicked the VBA program gathers the data from the cells (the objective and constraint coefficients, variable bounds, the constraint right-hand-side values, and the constraint relationship), sets up the model for solver and calls the solver. The results of the solver calculation are returned to the green cells in row 8.

The example uses the free Excel Solver add-in provided by Microsoft. Extended versions of this add-in are available from Front Line Systems. The add-in collection also has an LP/IP solver that solves small problems (up to 50 variables and constraints). A generalized network solver is available for network flow and transportation models. This solver can handle very large network models.

The model format of Figure 8 is a very simple representation of the linear optimization problem. More concise models can certainly be created for special cases and entered directly into the Excel Solver, however, using the more traditional form is certainly an easy way to get started with LP/IP modeling. It is not necessary for the student to be master of Excel or experienced in creating models for the Excel Solver.

This add-in, as all the other add-ins, does not attempt to duplicate or compete with the wonderful and powerful commercial tools for OR problem solving. Most real problems will be solved with programs that will be purchased from a vendor. The Excel add-ins are a good way to get started with OR modeling. They provide free access to a range of models and methods, not available otherwise. They have been available for several years and been improved or corrected many times. They are robust and easy to use.

Problems Section

This section provide a series of problems for instruction in operations research. Problems are arranged by general categories similar those included in the Models section. Most of the problems can be numerically solved using the Excel add-ins. Figure 9 shows the dialog for the LP problems. The buttons give access to the questions and answers. The stars indicate problem difficulty.
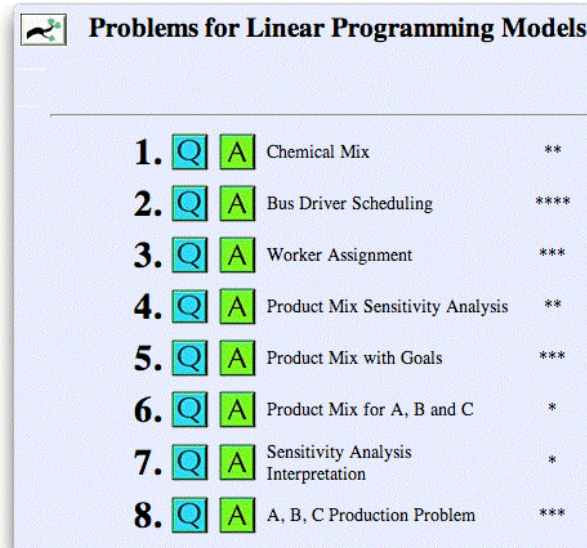

Figure 9. The LP problems

The ORMM Book over 400 problems and examples in all areas listed in the models section. All numerical problems have been solved in Excel with the add-ins in the Teach Operations Research Add-in Collection or the OR Models and Methods Add-in Collection.

Operations Management/Industrial Engineering (OM/IE)

This portion of the site is devoted to quantitative procedures that are helpful for the design and operation of manufacturing systems. The OM/IE site is really parallel to the ORMM site. It was created to focus on applications of OR. The Front Page of the OM/IE section is in Figure 10.
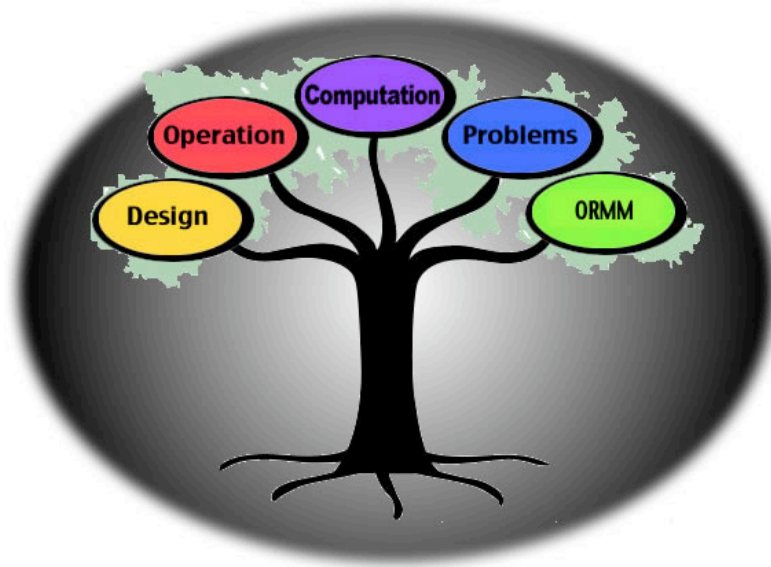

Figure 10. The Front Page of the OM/IE Section

The section is divided into four main categories. The Design section includes procedures that can be used while designing a system including: Economics, Facility Layout and Process Flow Analysis. The Operation section includes procedures that are useful during the day-to-day operation of a system including: Inventory Theory and Material Requirements Planning. Both design and operations are considered in the Computations section where one finds instructions for Microsoft Excel add-ins that address ten applications. The Problems section holds problems that illustrate the models and methods of this section.

The design subjects are often taught in an Industrial Engineering Program, while the operation subjects are often taught in an Operations Management Program, thus giving rise to the name of this portion (OM/IE).

The materials presented can be of value to students, faculty and practitioners. Students will find the tools to solve most analytical problems that are presented by familiar texts in OR, OM and IE. Faculty members will use the add-ins to construct interesting problems for use in classes. Practitioners may find the add-ins useful for small applications.

OM/IE Computation

This section describes add-ins that are useful for the design and analysis of manufacturing systems. Add-ins in the OM/IE Collection are listed in the dialog shown in Figure 11. Add-ins are installed by clicking the button next to the name. The add-ins are described in Appendix A.
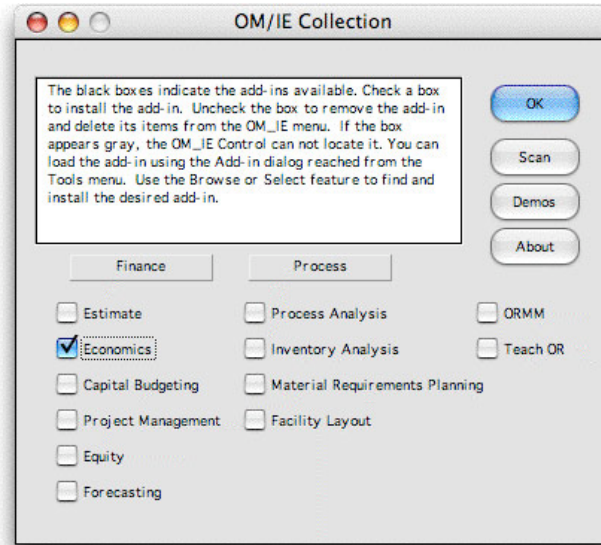

Figure 11. Operations Management/Industrial Engineering Collection

Each add-in puts a series of commands under the OM/IE menu. The menu for the Economics add-in is shown in Figure 12. The various menu items are explained on the web site. Selecting the Add Project presents a dialog for the evaluation of a cash flow.
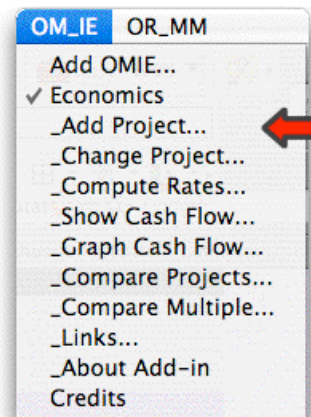

Figure 12. Economics Menu

Figure 13 shows the analysis of a the cash flow for a project with five components. The form was built by the Economics add-in. The student enters the data in the white cells and the results showing the net present worth and annual worth are computed in the yellow cells. The rate of return calculation requires an algorithm that initiatives with the *Compute Rates* command. The results are placed in the green cell (I5). The add-in also provides analyses including inflation, taxes and uncertainty.

The factors shown in column H are computed with functions programmed with VBA and provided by the add-in. These functions are similar to the built-in functions of Excel, but are called *user-defined functions* in the Excel Function category list.

	A	B	C	D	E	F	G	H	I
1	Project Definition			Periods		Rates (%)			Worth($)
2	Name	E6		Life (yrs)	10	MARR(/yr)	10.%	Present (Life)	82
3				Repetitions	1			Uniform (Life)	13
4				Study Period	10			Present (SP)	82
5								IRR	11.13%
6								Net Investment	
7									
8	Cash Flow Data - Amounts Negative for Expenditures and Positive for Revenues								
9	Index	Description	Amount($)	Type	Start	End	Parameter	Factor	CF. NPW($)
10	1	Investment	(2000)	Single	0	***	***	1.0000	(2000)
11	2	Revenue	600	Uniform	1	10	1	6.1446	3687
12	3	Op. Cost	(100)	Uniform	1	10	1	6.1446	(614)
13	4	Cost Inc./Yr	(50)	Gradient	2	10	1	22.8913	(1145)
14	5	Salvage	400	Single	10	***	***	0.3855	154
15									

Figure 13. Data form created by the Economics add-in

ORMM in Second Life

Second Life (SL) is a 3-dimensional virtual world. It is growing in popularity with over six million residents. It has been touted as the biggest advancement in user connectivity since the Internet. Time will tell if that is true, but it is a truly remarkable place. When you enroll in SL you are given a customizable avatar. The avatar can walk, fly and teleport among the thousands of virtual businesses, entertainment, and educational sites. There are mountains, rivers, beaches, oceans, forests and many developed areas. I have recently created a classroom in SL called *Art and Mathematics*. I will be investigating interactive approaches for teaching. Figure 14 shows two SL photographs or the classroom. OR is featured as an area of applied mathematics. Each OR related sign links to a page in the ORMM web site. Links on the walls connect to INFORMS and other OR related web sites.

Figure 14. Scenes from Second Life

Response to the ORMM site

The response to the site has been satisfying. Since 7/23/03 when counters were placed on the major topic pages of the site over 100,000 hits have measured on the front page of the ORMM site. The Excel add-in download page has almost the same number of hits. Of course, the hit

count does not indicate the number of persons that have read and used the site, but counters on other pages indicate that at least some persons browse to find specific topics. It is interesting that about 60% of the hits come from outside the US, so the ORMM site has worldwide appeal.

As of 6/14/2007, the link to the ORMM front page is most often selected from the INFORMS OR/MS Resource Collection: Noncommercial Software Packages list. It has maintained that distinction for some years. A Google search on Excel+Operations+Research or many of the main topics will find the ORMM site near the top of the search results. A Google group was formed on 6/27/2006. As of 6/14/2007, the group has 268 members.

The ORMM site won the 2006 Innovative Instructional Technology Awards Program Gold Award for Resource Development at the University of Texas at Austin. This is the top award in this competition. The book *Operations Research Models and Methods* (Jensen and Bard 2003) uses the add-in collection extensively for example and homework problems was published in 2003. The book won a runner-up award in the 2004 Robert W. Hamilton Book Award competition at the University of Texas. Sixty books were nominated from throughout the University community.

The *Testimonials* page on the site has a number of entries that indicate that students and practitioners do find the add-ins and web sites useful for learning. A review of some of the comments leaves little doubt that students and practitioners all over the world are using the site and have gained knowledge and skills that they would not have gained otherwise. A summary of a few of the comments are included in appendix B.

Several references have indicated application of the add-ins in practice. Kuchta, et al. (2004) and Shrimpton and Newman (2005) use the Network Solver add-in for very large network models. Wlodarczyk (2003) uses the queuing add-in for a publishing application. Zoghby (2000) uses the mathematical programming add-in for semiconductor Fab planning.

In the Operations Research/Industrial Engineering group of the Mechanical Engineering Department at UT-Austin the faculty have been using the site and the add-ins to support several courses since 2003. The Operations Research Models course (ME366L) was completely redesigned to use the materials.

In 2006-2007, the author developed and taught a web based course on Engineering Finance. The *Estimate*, *Economics*, *Project Management*, and *Random Variables* add-ins are an integral part of the class. Web-based delivery of course materials will probably be a growing part of UT instruction in the future.

Conclusions

I conclude by comparing what the ORMM web site is with what it is not. The site has a broad selection of OR models and applications, rather than in-depth coverage of a particular topic. It is a web-based survey of introductory OR topics, rather than an introductory textbook in OR. Textbooks clearly have the edge in presenting the mathematics. The site can, however, support

any introductory text in OR and a variety of texts in OM and IE. It does not attempt to provide the theoretical basis for the OR methods, rather it provides tools for implementing the methods. It does not provide extensive references to source material. Most of the techniques covered in the site are well known and covered extensively in books. References can be found in scholarly articles or web-based indices. An Excel add-in is not as powerful as a commercial product nor does it embody the latest algorithmic research. The add-ins cannot compete with the investment of commercial firms in programming and marketing. Experience with OR models and methods using the add-ins will encourage serious analysts to seek more powerful commercial products. The site is a free resource, open to everyone with a web connection, and visited by many persons from throughout the world.

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