MSEL
MODELLING IN SCIENCE EDUCATION AND LEARNING

Modelling in Science Education and Learning
Volume 4, No. 25, 2011.
Instituto Universitario de Matemática Pura y Aplicada

Applied mathematical modelling for Industrial Engineers

Josefa Mula, Raúl Poler
Universidad Politécnica de Valencia
fmula@cigip.upv.es, rpoler@cigip.upv.es

Abstract

El aprendizaje de técnicas de modelización matemática puede resultar en un proceso largo y tedioso para estudiantes de Ingeniería de Organización Industrial. Es necesario combinar de una forma equilibrada las enseñanzas teóricas con el modelado de casos de estudio reales. Para hacer más flexible el proceso de enseñanza teórica, se proporcionan herramientas multimedia de aprendizaje autónomo. Un factor clave es evolucionar de modelos simples resueltos a través de programas educativos, tales como WinQSB u hojas de cálculo con solucionadores embebidos a modelos más complejos desarrollados con diversos solucionadores comerciales (CPLEX, GUROBI, XPRESS, etc.) El objetivo de esta comunicación es presentar una metodología innovadora para enseñar técnicas de modelización matemática basada en: (a) el equilibrio de las enseñanzas teóricas y prácticas; (b) el uso de herramientas multimedia autodidácticas; y (c) la formulación y resolución de casos de estudio reales a través de diferentes solucionadores.

The learning of mathematical modelling techniques can result in a long and tedious process for Industrial Organization Engineering students. It is necessary to combine in a balanced way the theoretical teachings with the modelling of real study cases. In order to make more flexible the theoretical teaching process, multimedia tools of autodidactic learning are provided. A key factor is to evolve from simple models solved through educational programs, such as WinQSB or spreadsheets with embedded solvers to more complex models developed with a high level language of mathematical programming as MPL or GAMS where the models are solved with diverse commercial solvers (CPLEX, GUROBI, XPRESS, etc.) The objective of this paper is to present an innovative methodology to teach mathematical modelling techniques based in: (i) the balance of the theoretical and practical teachings; (ii) the use of multimedia autodidactic tools; and (iii) the formulation and resolution of real study cases through different solvers.

Keywords: Learning, mathematical modelling, industrial engineers.

1 Introduction

From their beginnings, one of the most interesting applications for the optimization tools generated by the mathematical modelling was the operations management problems (demand forecasting, production planning, inventory management, etc.) These problems have in general a great number of variables and they address a horizon of multiple time periods.

There are many commercially available optimization software and the computer hardware is powerful, therefore the need of designing or implementing optimization algorithms has been reduced in favour of modelling, evaluating, using existing software, interpreting solutions, and understanding decision support requirements (Lasdon and Liebman, 1998).

The Industrial Engineer is formed in the areas of Production Management, Business Management, Economy and, other technological topics related with the managerial world. The courses include: Design, Planning and Management of Production-Inventory Systems, Quantitative Methods for Industrial Organization, Study of the Work, Commercial Management, Financial Management, Business Strategy and Politics, Industrial and Technological Politics, Business Competitiveness and Innovation. The educational program is designed so that the student carries out issues in real companies along the whole course, while the final project has a clearly managerial orientation.

We teach mathematical modelling to undergraduate students majoring in the Industrial Engineering program at the Universidad Politécnica de Valencia at Alcoy, Spain, since 1994 inside of the core course "Quantitative Methods for Industrial Organization (QMIO)". Mula and Poler (2007) analyze in detail the QMIO core subject as a study discipline in the Industrial Organization Engineering degree in the Spanish universities.

In Alcoy, the QMIO course has 50 engineering students and is mainly oriented to modelling and solving proposed problems and real case studies. Our main innovation is to balance the theoretical and practical teachings through multimedia autodidactic tools and real case studies using cooperative active learning methods instead of the traditional lecture format.

The paper is organized as follows. Section 2 shows the balance of the theoretical and practical teachings in the QMIO course and describes the educational method used. Section 3 exposes the utility of multimedia autodidactic tools as a support to the educational method for the learning of mathematical programming. Section 4 describes the way the case studies are set out by the students of the QMIO course in order to develop their practical assignments. Section 5 shows the results of the student satisfaction questionnaires related to the QMIO course. Finally, section 6 concludes the paper with a summary.

2 Balance of the theoretical and practical teachings

The educational method as teaching instrument and learning of the student should have a series of qualities, that is:

i) *Scientific clarity and of exposition.* The fundamental objective of the educational method is the preparation and education of future professionals in the field of the Industrial Organization Engineering. Of course, it cannot be exclusively practical (with the only purpose of solving well-known problems and experienced in its resolution) but rather it should contribute and be based on scientific and technical knowledge that help him to propose and solve new situations, that are presented in the managerial reality.

ii) *Motivation of the student.* The educational method should be able to capture the interest of the student, motivating him in the knowledge of the course and facilitating him the own development of his capacity. At the same time, the instructor must clarify him the possibilities that the quantitative methods offer him in the moment of their formation, but fundamentally in their future performance to analyze, define and solve real world problems.

iii) *Performance and responsibility.* It is appropriate to highlight the importance that the Assignments and its Evaluation will have for the students. In fact the motivation and responsibility of the students can be stimulated if are used references, comments, practical connections, and applications of the explained topics and tools.

In this context, the QMIO course has the following general learning objectives for the students:

- Know the concepts of characteristic, processes and tools of the quantitative methods.
- Understand the nature of the optimization problems and their modelling and resolution through Linear Programming (LP). Learn the general logic of the Simplex method and be able to apply it to the resolution of the models.
- Improve the modelling in the context of Mixed and Integer Linear Programming (MILP) and to outline the different resolution techniques.
- Be able to develop the Nonlinear Programming (NLP) in the cases related to functions of 1 or several variables, uni or multi-modal and unconstrained or constrained. Know algorithms and resolution methods and analysis of the solution.
- Understand the language of the Network Modelling and to model the different types of problems that can be represented by means of networks.
- Know the different components of an inventory system (inventory level, launching, lead time, shortage and safety stock). Understand the EOQ model and its extensions.
- Be able to define the queue problems and their analytical modelling. Understand the different queue models and their resolution.
- Learn the simulation and their importance for the resolution of complex problems. Understand the Monte-Carlo methodology for the resolution of simulation problems. Develop the simulation of queue lines.
- Know the competition problems and develop the decision theory.
- Understand the impact in the problem of the information value and the complexity of the real games.
- Learn the philosophy of resolution of Dynamic Programming (DP) problems so much in deterministic context as stochastic.
- Understand the concepts of Markov Chains as a special type of stochastic process.

Table 1 lists the topics in the order covered and the hours dedicated to them in the QMIO course during the two semesters of 2009/2010.

Topic	Hours
Semester A	
Introduction	2,5
Linear Programming	14,5
Integer Programming	6,5
Nonlinear Programming	7,5
Network Modelling	13
Inventory Management	8
Queue Theory	9
Semester B	
Simulation	14
Decision Theory	16
Theory of Games	9
Dynamic Programming	12
Markov Processes	9

Table 25.1: Topics and hours for the QMIO course in 2009/20010.

Quantitative Methods for Industrial Organization (QMIO) Total credits (12)			
Theoretical credits	**6**	**Practical credits**	**6**
Master class credits	4	*Practical credits in the classroom*	2
Seminar credits	2	*Practical credits in the computer lab*	4

Table 25.2: Distribution of practical and theoretical credits of the QMIO course.

The topics of linear programming, integer programming, nonlinear programming and dynamic programming, i.e. mathematical programming, accounted for 35.83% of the total hours of the QMIO course. Also, mathematical programming models were covered during the sessions of the other topics such as network modelling, inventory management and theory of games.

It seems unquestionable that in the education of an Industrial Organization Engineer the practical sessions are fundamental, because although the scientific experience and the knowledge of the theory are indispensable, the engineer is fundamentally an action professional, and for him the practical application of their scientific-technical knowledge is indispensable. Table 2 shows the distribution of the theoretical and practical credits (10 hours) of the QMIO course.

It can be observed the balance between the theoretical (6) and practical (6) credits. The theoretical credits are given in the traditional formats of master class and seminar. With respect to the practical credits it is important to highlight the differences between the practical credits in the classroom and the practical credits in the computer lab.

2.1 Practical credits in the classroom

West et al. (1991), Liebman (1994) and Fellers (1996) highly recommend the use of active learning in operations research in the classroom because students learn more and retain ideas longer. Active learning is cooperative when students work in teams. Lasdon and Liebman (1998) propose some examples of group activities. During the practical credits in the classroom of the QMIO course, for instance, student teams (3 or 4 students) solve problems proposed by the instructor, who acts as facilitator. Thus, problems are done collaboratively by groups who develop and share insights cooperatively. Next, the teams explain to the class the formulated models and the raised solutions while that the instructor clarifies these solutions.

2.2 Practical credits in the computer lab

The attendance to the practical sessions in the computer lab is mandatory. During the practical credits in the computer lab, students carry out a total of 10 practical sessions and 4 assignments based on real case studies proposed by the students (2 each semester). The practical sessions are described in Table 3.

Through the following practical sessions and assignments, the new practitioners begin to understand the tools that can use (finding their advantages and limitations) to build mathematical models in order to solve real world problems. Also, the students improve their modelling skills by formulating these real problems, solving them, and analyzing and understanding the solution.

The assignments are worked in teams of 3 students. The teams are constituted by the students, freely. The duration of the practical assignments will be of 4 weeks: 1 week of explanation by the instructor and modelling and resolution of simple examples by the students (EFI), 2 weeks of realization and tutorial sessions (TS), 1 week of public exposition by the teams (PE). The practical sessions and assignments are scheduled according to Table 4.

Description of the practical sessions and assignments of the QMIO course.

2.3 Evaluation of the theoretical and practical credits

There is a final exam that accounts for the 60% of the final mark of the course. The students can use during the exam any bibliographic material, therefore, they do not require to memorize any algorithm or technique but learn to use them.

The marks of the assignments suppose a 40% of the final mark of the course. Students should obtain in the final theoretical exam a mark equal or superior at 40% to be averaged with the mark of the practical assignments.

The mark of the practical assignments is carried out according to the following scale:

- Interest, applicability and difficulty of the problem (20%). The more real it is the problem, higher it will be the punctuation obtained in this point. In case a group does not know how to outline a problem, the instructor will provide them one, but students will obtain a 0 in this point.
- Modelling, resolution and evaluation of the results (50%). This section takes into account the correct application of the used techniques/solvers as well as the conclusions and analysis

Name	Description	Software	Assignment
LINEAR PROGRAMMING	The practical session in computer lab consists on the handling of the software WINQSB in their section of Linear and Integer Programming, the Solver component of Microsoft Excel and the MPL modelling language with the CPLEX solver.	WinQSB (Linear and Integer programming) Microsoft Excel (Solver) MPL (CPLEX)	The students apply the linear programming theoretical and practical issues to a real problem proposed by them and the results are presented in a public exposition.
INTEGER PROGRAMMING/ NONLINEAR PROGRAMMING	The practical session in computer lab consists on the handling of the software WINQSB in their section of Linear and Integer Programming and Nonlinear Programming, the Solver component of Microsoft Excel and the MPL modelling language with the CONOPT solver.	WinQSB (Linear and Integer programming/Nonlinear programming) Microsoft Excel (Solver) MPL (CONOPT)	NO
NETWORK MODELLING	The practical session in computer lab consists on the handling of the software WINQSB in their section of Network Modelling, the Grafos application, the Solver component of Microsoft Excel and the MPL modelling language with the CPLEX solver.	WinQSB (Network Modelling) Grafos Microsoft Excel (Solver) MPL (CPLEX)	The students apply the network modelling theoretical and practical issues to a real problem proposed by them and the results are presented in a public exposition. The network modelling problems that are also modelled via linear programming (if possible) are positively considered.
INVENTORY THEORY	The practical session in computer lab consists on the handling of the software WINQSB in their section of Inventory Theory and System.	WINQSB (Inventory Theory and System)	NO
QUEUE THEORY	The practical session in computer lab consists on the resolution of a case study proposed by the instructor through Microsoft Excel.	Microsoft Excel	NO
SIMULATION	The practical session in computer lab consists on the handling of the software Microsoft Excel for the resolution of simulation problems.	Microsoft Excel	The students apply the simulation theoretical and practical issues to a case study proposed by the instructor. Each team must select a different case study.
DECISION THEORY	The practical session consists on the handling of ADGIP for the representation and resolution of decision trees.	DTGIP and WINQSB (Decision Analysis)	The students solve a case study proposed by the instructor (same for all teams) and they defend in public the decisions that take for their modelling and resolution.
THEORY OF GAMES	The practical session in computer lab consists on the handling of the software WINQSB in their section of Decision Analysis. Also, the use of Microsoft Excel for the resolution of game theory problems.	WINQSB (Decision Analysis), Microsoft Excel and GTGIP	NO
DYNAMIC PROGRAMMING	The practical session in computer lab consists on the handling of the software WINQSB in their section of Dynamic Programming.	WINQSB (Dynamic Programming) and DPGIP	NO
MARKOV PROCESSES	The practical session in computer lab consists on the handling of the CadMGIP for the resolution of markov chain problems.	WINQSB (Markov Process) and MPGIP	NO

Table 25.3: Description of the practical sessions and assignments of the QMIO course.

A-semester	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
LINEAR PROGRAMMING			EFI	TS	TS	PE								
INTEGER PROGRAMMING / NONLINEAR PROGRAMMING					EFI									
NETWORK MODELLING							EFI	TS	TS	PE				
INVENTORY THEORY									EFI					
QUEUE THEORY											EFI			
B-semester														
SIMULATION			EFI	TS	TS	PE								
DECISION THEORY					EFI	TS	TS	PE						
THEORY OF GAMES							EFI							
DYNAMIC PROGRAMMING									EFI					
MARKOV PROCESSES											EFI			

Table 25.4: Scheduling of the practical sessions and assignments of the QMIO course.

of the results.

- Written report and public exposition (30%). It is required to the students that include the different stages of the proposed case study in the reports of the assignments (Exposition of the case, modelling, resolution and validation of the model, validation of the solution, implementation of the results, and recommendations) rather than only to present the resolution of an academic problem by means of methods and computational tools. Also, it is positively considered that the works are exposed jointly by all the members of the group, anyway the presence of the 3 components of the team is obligatory in the moment of the exposition because the instructor will make questions to the students that do not expose any part of the work.

3 Multimedia autodidactic tools

The basic bibliography for the students of the QMIO course is formed for four books written by Vicens et al. (1997a, 1997b, 1999) and Companys et al. (1999). The books by Vicens et al. (1997a, 1997b) contain theory and algorithm while the books by Vicens et al. (1999) and Companys et al. (1999) include problems and applications. Other important complementary texts, among others, to consider are Winston (2005), Hillier and Lieberman (2001), y Taha (2005). However, for an innovator course with a good coverage of computational practical sessions and real applications other tools and materials are required.

We provide to the students of the QMIO course notes on slides, an extended list of books, journal articles, and computer programs (DTGIP, GTGIP, DPGIP, MPGIP, etc.). The computer programs are, furthermore, used by the instructor as a tool that facilitates the learning in theoretical sessions.

Also, in the context of a project of educational innovation of the Universidad Politécnica de Valencia we have developed a multimedia autodidactic tool (see Mula et al. 2003) to help students to understand the basics of linear programming with tutorials on the use of the Excel Solver and the Linear and Integer Programming module of WinQSB (Chang, 1998). This tool is mainly oriented to new production management practitioners and describes several linear programming models for production planning including the well known Material Requirement

Planning (Orlicky, 1975). With respect to the autodidactic learning of the MPL modelling language, students use the on-line tutorial.

4 Case studies

The group formulates a problem that they have defined from a real company and solves it using the Excel solver, WinQSB, and/or MPL (see section 4.1) and presents the model and solution in class. The students can find two examples of real case studies in the multimedia CD by Mula et al. (2003).

Each group chooses its case study. The groups visit a company, chosen by them, and they take data, pictures and/or videotape images that can be useful in order to define the case study. Once the group has defined the problem, they analyze it, formulate the model, and solve it. Then, the group should elaborate the report and the public exposition with the modelling process and obtained results. The students can consult the difficulties that have arisen and can request orientation by means of tutorial sessions with the instructor.

The main advantage of this methodology is, clearly, the direct contact that the students have with the companies, through of their own case studies and because of the visualization of the cases presented by the rest of students.

With respect to the disadvantages, it could seem that the fact that the students have to present problems of real cases can suppose them true headaches and even serious difficulties to obtain the appropriate data. In the case of difficulties, the instructors mediate to facilitate the contact with the companies. It has never been given the circumstance in which the students have had to request a prepared case to the instructor. On the contrary, the students are usually satisfied with the visits done to the companies, where they usually carry out more than a practical assignment. It also has happened that companies request the works carried out the students and satisfied with them, they offer them the possibility to incorporate themselves to the own company. Some examples of case studies proposed and solved by the students are listed below:

- Production planning problems in manufacturing companies,
- distribution of effects in different bank entities,
- mixture problem for cheese production,
- inventory management in a garage,
- optimization of the technical inspection of vehicles,
- a scheduling system for supermarket cashiers,
- programming of work shifts in different companies,
- optimal policy of substitution of vehicles or equipment in different companies.

4.1 Different solvers

Optimization software is readily available, powerful and easy to use. The students of the QMIO course learn to handle:

- an educational program such as WINQSB (Chang, 1998),
- a spreadsheet optimizer (Excel Solver), and
- a high level language for mathematical programming models such as MPL (Maximal Software, 2000). Resolution is carried out with the optimization solver CPLEX (CPLEX Optimization Co, 1994) for linear programming models and mixed integer linear problems and the optimization solver for nonlinear programming CONOPT (Drud, 1994).

The educational approach is to learn how to implement, solve and understand results of models using this software. Also, the students learn the existence of the algebraic languages AMPL (Fourer et al. 1993), GAMS (Brooke et al. 1992) and LINGO (Schrage, 1991),among others. And other solvers, including LSGRG2 (Smith and Lasdon, 1992), GUROBI (Bixby and Rothberg, 2003), and free distribution software. New Industrial Organization Engineers should know the fundamental optimization tools and understand their capabilities and limitations to be prepared to choose an appropriate one if required.

5 Teaching evaluation

The Universidad Politécnica de Valencia evaluates the student satisfaction with respect to the teaching effectiveness through the ICE (Institute of Education Science). The ICE gives the students of each course a mid-semester feedback questionnaire with 19 questions dealing with student satisfaction with the course and the instructor.

Compared with other courses with no innovator teaching techniques the QMIO course reaches better punctuations, especially in the sections corresponding to applicability and use of resources (this section has gone improving from year to year due to the introduction of new techniques and tools).

6 Conclusions

We believe that the balance of the theoretical and practical teaching, the use of multimedia autodidactic tools, and the formulation and resolution of real case studies through different solvers by students, help them to understand the power of the mathematical modelling as an optimization tool to solve real industrial problems. Furthermore, in order to guarantee the learning objectives in the area of Industrial Organization, it is required the student's contact with the managerial reality. Therefore, the student should dedicate a great part from his time to the resolution of real cases, provided by the instructor or extracted of the reality for himself.

Of course, the active learning through the practical sessions in the classroom and in the computer lab, as well as using the multimedia autodidactic tools, and working in teams to propose, model and solve a real world problem requires more effort by the part of students but also the benefits will be higher. By the part of the instructor, the effort of preparing and evaluating the practical sessions and assignments is considerable with respect to prepare only theoretical sessions following the master class and seminar format. Nevertheless, this approach is also successfully applied in other courses of the Industrial Organization Engineering program such as "Design, Planning and Management of Production-Inventory Systems" and "Study of the Work".

References

[1] Brooke, A., Kendick, D. and Meeraus, A. (1992) GAMS, a user's guide, Boyd and Fraser, Danvers, Massachusetts.

[2] Bixby, R. E., Rothberg, E. (2003). Solving linear and integer programs. MPI Informatik ADFOCS.

[3] Chang, Y.L. (1998) WinQSB. Decisión support software for MS/OM, Ed. John Wiley & Sons, Inc.

[4] Companys, R., Vicens, E., Poler, R., Albarracín, J.M. and Palmer, M.E. (1999) Problemas de Métodos Cuantitativos. Volumen II. Ed. SPUPV-99.4152. CPLEX Optimization Co. (1994) Using the CPLEX callable library.

[5] Drud, A. (1994) CONOPT - a large-scale GRG code, ORSA Journal on Computing 6, 2, 207-216.

[6] Fellers, J.W. (1996) Using the cooperative learning model to teach students people skills, Interfaces 26, 5, 42-49.

[7] Fourer, R., Gay, G. and Kernighan, B. (1993) AMPL: A modelling language for mathematical programming, Boyd and Fraser, Danvers, Massachusetts.

[8] Hillier, F.S., Lieberman (2001) Investigación de operaciones. 7ª Edición. Ed. McGraw-Hill. Lasdon, L. and Liebman, J.S. (1998) The teachers forum: teaching nonlinear programming using cooperative active learning, Interfaces 28, 4, 119-132.

[9] Liebman, J.S. (1994) New approaches in operations research education, International Transactions of Operational Research 1, 2, 189-196.

[10] Maximal Software Corporation (2000) MPL modelling system. Release 4.11, USA.

[11] Mula, J., Poler, R. (2007) Configuración de la materia troncal de métodos cuantitativos de organización industrial en las universidades españolas. Revista de Métodos Cuantitativos para la Economía y la Empresa 3, 3-19.

[12] Mula, J., Poler, R. and Rodríguez, A. (2003) Programación Lineal Continua. Planificación de Requerimientos de Materiales (MRP). CD interactivo. Ed. SPUPV-03.0186P12.

[13] Orlicky, J. (1975) Material Requirements Planning, McGraw Hill, London.

[14] Schrage, L. (1991) Lindo, an optimization modelling system, Boyd and Fraser, Danvers, Massachusetts.

[15] Smith, S. and Lasdon, L. (1992) Solving large sparse nonlinear programs using GRG, ORSA Journal on Computing 4, 1, 3-15.

[16] Taha, H.A. (2005) Investigación de operaciones. 7ª Edición. Prentice-Hall, México. Vicens, E., Ortiz, A. and Guarch, J.J. (1997a) Métodos Cuantitativos. Volumen I. Ed. SPUPV-97.475.

[17] Vicens, E., Ortiz, A., Poler, R., Sempere, F., Alemany, M.M. and Alfaro, J.J. (1999) Problemas de Métodos Cuantitativos. Volumen I. Ed. SPUPV-99.4154.

[18] Vicens, E., Poler, R., Albarracín, J.M. and Palmer, M.E. (1997b) Métodos Cuantitativos. Volumen II. Ed. SPUPV-99.4050.

[19] West, C.K., Farmer, J.A. and Wolf, P.M. (1991) Instructional design: Implications from cognitive science, Allyn and Bacon, Needham Heights, Massachusetts.

[20] Winston, W.L. (2005) Investigación de Operaciones. Aplicaciones y Algoritmos. Ed. Thomson.