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# TEACHING WITH THE PROBLEM SOLVING POWER OF SIMULATION

Charles R. Standridge

301 West Fulton
School of Engineering
Padnos College of Engineering and Computing
Grand Valley State University
Grand Rapids, MI 49504 U.S.A.

## ABSTRACT

A strategic curriculum revision concerning simulation methods, production operations, and facility layout and material handling courses in a product design and manufacturing engineering curriculum is described. The revision is based on two ideas. Simulation is best taught in the context of its applications. Simulation is both a vital analysis tool and a vital teaching approach for examining the time dynamics of production systems such as work cells, kanban systems, and flexible manufacturing systems as well as material movement systems within facilities and logistics systems for material movement over long distances. The simulation methods classes are removed from the curriculum. Simulation methods are integrated into revised production operations courses. A traditional material handling and facilities layout course is revised into a material movement course that includes supply chain logistics. Simulation based laboratories, case studies and case problems are used extensively in both of the revised courses.

## 1 INTRODUCTION

The first simulation course in fields such as industrial engineering, manufacturing engineering, product design and manufacturing engineering, and management science should definitively demonstrate the relevance of simulation in a manufacturing world driven by lean principles and supply chain management. Service section application areas, such as health care delivery, should be considered as well.

In keeping with this idea, many authors have argued in a favor of case based teaching methods. Shore and Plager (1978) advocated for this approach early on. Standridge (2000) discusses an application of the case based approach to simulation instruction. Case studies show how simulation methods address issues involving system design, operations, and management.

Properly constructed cases provide a "metaphor' for real problems and allow students to "simulate" the role of a practicing engineer or manager (Shapiro 1984). Centeno (Standridge et al. 2005) reinforced these arguments in her discussion of the use of case problems in an undergraduate industrial engineering simulation class. Shultz and Geiger (2005) expanded the mechanisms used to teach case studies to include multimedia presentations showing the actual operation of the system under study.

Furthermore, Richards et al. (1995) discuss the following general benefits of using cases in engineering education:

- *Relevance*. Actual representation of real design and operations issues faced by engineers and managers.
- *Motivation for students.* The realism of the cases provides an incentive for the students to become more involved in the material they are studying.
- *Consolidation/Integration.* Each case requires the application of multiple concepts and techniques in an integrated fashion to address a single set of issues.
- *Transfer.* Cases give students experience that can be applied to subsequent cases, other course work, and on the job situations.

Given all these arguments in favor of using cases in an introductory simulation course, the idea of teaching simulation in the context of its application seems to be firmly established.

Recently, the School of Engineering at Grand Valley State University (GVSU) decided to evolve the manufacturing engineering program into a product design and manufacturing engineering program at both the undergraduate and masters levels. This resulted in an examination of the curriculum which raised the following issue: The same applications were covered in the introductory simulation courses as in the introductory production opera-

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tions courses. Would it be possible to combine these two courses, both at the undergraduate and masters level?

Reflection on this question led to the realization that a strategic revision of the curriculum concerning the introductory simulation and production operations courses was needed. It was decided that this revision should be based on the following two basic ideas:

- Simulation is best taught in the context of its applications.
- Simulation is both a vital analysis tool and a vital teaching approach for examining the time dynamics of production as well as of material movement systems.

It seemed reasonable to improve the way students learn about the operation of modern production systems by including simulations of the them in the teaching material. In addition, there seemed to be great potential for improving the analysis of such systems by combining the basic analytic techniques taught in the production operations courses with the simulation techniques taught in the simulation courses. Furthermore, this thinking was extended to include the materials handling and facilities layout course. The content and teaching approach used in each of the combined courses: production operations integrated with simulation and material movement integrated with simulation will be presented.

## 2 THE STRAGIC CURRICULUM CHANGE

Figure 1 shows the organization of the curriculum before the strategic change. The undergraduate manufacturing program had two required courses: EGR 371 Manufacturing Systems Simulation and EGR 373 Production Scheduling and Control that could be taken in either order. Advanced undergraduates could elect EGR 642 Material Handling and Facilities Layout. Graduate students in the manufacturing operations program were required to take at least two of the three 600 level courses in any order: EGR 642, EGR 640 Production Operations Models, and EGR 643 Manufacturing Simulation.

EGR 371 and EGR 643 were similar courses. Both relied on a case based approach for introducing simulation methods and applications (Standridge 2000). Both modeling and experimentation methods were presented. Case studies and problems were drawn from multiple areas including lean manufacturing, material handling, and logistics. Graduate students were required to perform a term project of their own design while the undergraduate were given an additional case problem. The undergraduate students used ProModel (Harrell, Ghosh, and Bowden 2000) while the graduate students used AutoMod (Banks 2004).

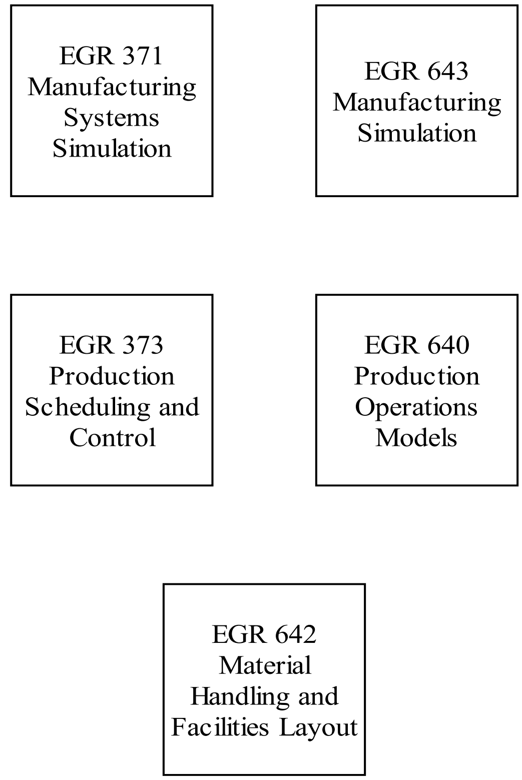


Figure 1: Curriculum Before Strategic Change

EGR 373 and EGR 640 were parallel courses covering traditional production scheduling and control topics as well as the application of queuing, inventory, and linear programming models. Some modern manufacturing topics such as cellular design, kanban systems, and value stream mapping were introduced. EGR 373 was for undergraduate students and EGR 640 was for graduate students.

Several course content issues were identified when the curriculum review was performed as a part of evolving the manufacturing engineering programs into the product design and manufacturing engineering programs. These included the following:

- There was redundant topical coverage between EGR 371 / 643 (the simulation courses) and EGR 373 / 640 (the production operations courses) courses. For example, how to set inventory and kanban levels was covered in both courses. Determining the number of machines was also covered twice, for a deterministic environment in the production operations courses and for a stochastic environment in the simulation courses.
- Students could take the production operations and simulation courses in either order. Thus, the simulation course instructor could not count on students knowing the production operations material

and vice-versa. For student scheduling reasons, the sequencing of the courses could not be fixed.

- Some topics such as queuing models for push-oriented assembly lines and traditional inventory models did not seem relevant in introductory application based courses focused on lean oriented production environments.
- The material handling and facilities layout course did not cover topics related to supply chain management, though some coverage was provided in the simulation courses.

The existing courses were based on an organization of topics by methods. Simulation methods and applications were taught in simulation courses. Analytic methods and production applications were taught in production operations courses. Analytic methods for facilities layout and within plant material handling applications were taught in a separate course.

In the new organization of the curriculum, courses were organized by application topic with analytic and simulation methods integrated to provide effective solutions to application issues. This new organization is shown in Figure 2.

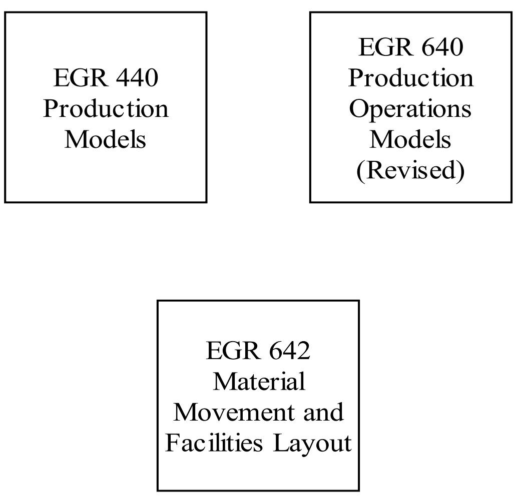


Figure 2: Curriculum After Strategic Change

The courses EGR 440 Production Models and the revised EGR 640 Production Operations Models were created by integrating existing courses: EGR 371 / EGR 373 for EGR 440 as well as the EGR 640 and EGR 643 for the new EGR 640. This integration was accomplished by shifting topics to other courses, eliminating topics, and gaining efficiencies in coverage as follows:

- Push system topics such as queuing models for push-oriented assembly lines and materials requirements planning computations were eliminated.
- All coverage of supply chain management logistics was moved from the existing simulation classes to EGR 642.
- All coverage of applications requiring optimization models was moved to a new course, EGR 641 Applied Optimization.
- Applications such as setting the number of machines at a workstation or setting an inventory level use both analytic and simulation models. The discussion of both types of models is isolated in one course and requires less time than when these topics were taught in two courses.

In the following sections, the new courses will be described in detail.

## 3 EGR 440 PRODUCTION MODELS

EGR 440 contains the following major topics:

- An overview of lean manufacturing, based on Tapping, Luyster, and Shukar (2002), and including value stream mapping.
- Simulation methods including the process world view for modeling, experiment design and analysis, the operation of the simulation engine, and fitting distribution functions to data.
- A discussion of why simulation is a necessary extension of lean methods based on (Marvel and Standridge 2006). Simulation can be used to deal with the random and structural variation in systems, to examine the interaction of system components, and to predict future performance. Thus, simulation addresses the deficiencies in lean methods.
- Presentation of traditional and contemporary models for analyzing individual system components: workstations and inventories.
- Analysis of basic systems: serial lines and job shops. The joint use of analytic methods and simulation is emphasized. For example, analytic methods are used to set the number of machines at each station in the job shop, assuming constant demand and processing times. Simulation is used to determine how many additional machines at which stations are required to meet lead time targets given the stochastic nature of customer orders and processing times.
- Design and analysis of pull oriented manufacturing systems that use kanban or CONWIP controls (Hopp and Spearman, 2000). Analytic methods are used to set the number of kanbans as well as finished goods inventory levels. Simulation is

used to determine how much additional inventory is needed to meet customer service level targets given the random nature of customer demand. Maas and Standridge (2005) provide an industrial application of this combined use of analytic models and simulation models.
- Design and analysis of manufacturing work cells. Traditional cell design methods are used to design the cell, including the assignment of workers to tasks. Simulation is used to validate the design of the cell. Validation of worker movement includes a trace of the path each worker takes through the cell. Simulation is used to assess the robustness of the cell in face of random arrivals of raw materials as well as the effectiveness of alternative assignments of workers to tasks. An industrial application of using simulation to validate and extend a manufacturing cell design is given by Grimard, Marvel, and Standridge (2005).
- Design and analysis of order scheduling in a flexible manufacturing cell. A schedule produced using a heuristic optimization procedure is validated and compared to a more ad hoc scheduling technique.

Student assignments include the following.

- Tutorials to learn a simulation environment as well as distribution function fitting software.
- Computer laboratory assignments for simulation result analysis, simulation engine operations, and analytic models of workstations and inventories.
- Experimentation with case study models provided by the instructor to better understand the operation of serial lines, job shops, kanban systems, work cells, and flexible manufacturing systems.
- Case problems that require analysis using analytic models as well as simulation model building and experimentation.
- A final examination emphasizing the basic principles of how the systems studied in the course operate.

To illustrate, consider the student assignments for the pull oriented manufacturing course component. The case study describes a pull oriented manufacturing system. A finished goods inventory (FGI) level is determined using analytic methods and is based on the average time to replace a part removed form the FGI. Simulation experiments are used to determine the customer service level when the analytically derived FGI level is used as well as the minimum FGI level that results in a 100% service level.

Students are asked to conduct further experiments with the model to determine the FGI inventory level that results in a 99% customer service level. In addition, students are required to print a trace of all activities triggered by one customer demand to help gain greater insight into the behavior of a pull system.

A case problem is also assigned concerning this material. Students are asked to convert a push oriented serial line into a pull oriented CONWIP system. To complete this assignment, a student must do the following:

- Analytically determine a finished goods inventory level based on the average time to replace a part.
- Model the serial line.
- Perform simulation experiments to determine the minimum CONWIP level that does not constrain throughput.
- Perform additional simulation experiments to find the minimum finished goods inventory level that results in a 99% customer service level

## 4 EGR 640

EGR 640 is the masters level version of EGR 440. As it is an introductory course to the same material, EGR 640 is similar to EGR 440. The major differences are that the graduate students, the vast majority of whom are employed full time in industry, are required to do a term project based on their own experience. AutoMod is used instead of ProModel.

## 5 EGR 642

Students taking EGR 642 are assumed to have knowledge of simulation methods and have practiced model building and experimentation as was required to complete EGR 440 or EGR 640.

The first third of EGR 642 covers traditional plant layout topics. The second third of the course covers inplant material movement and storage: conveyors, AGV systems, and automated storage and retrieval systems (AS/RS). The final third of the course discusses supply chain logistics.

The teaching strategy for the last two thirds of the course is similar to that used in EGR 440 and EGR 640. A case study is presented. Students are assigned to perform a case problem based on the case study. A term project is required as well.

The case studies and problems concerning in-plant material handling use animation to help students understand the operation of these systems. Animations show packages flowing and being routed on conveyors as well as AGV's moving on guide paths in a layout. Furthermore, students learn the AutoMod modeling constructs specific to these types of systems including conveyors, guide paths, control points, and AGV's.

The case studies and problems concerning supply chain logistics show the similarities with modeling production systems. Travel times replace operation times. Resources model trucks and train cars instead of machines. Inventory levels need to be set using analytic computations as well as simulation models. Customer service levels are an important performance measure in both types of systems.

## 6 SUMMARY

Organizing courses based on the application topics of interest, instead of the analytic or simulation methods of interest, resulted in a strategic re-organization of the curriculum. Simulation methods are integrated with analytic approaches for the teaching of production operations as well as material handling and supply chain logistics. A case based approach is employed where students use a combination of analytic and simulation models to address issues in pull systems, work cell design, flexible manufacturing, conveyor systems, AGV systems, and supply chain logistics. Students perform computer-based laboratories and case problems to learn how these systems operate.

The traditional introductory simulation courses have been eliminated, with no regrets on the part of the instructor. The faculty have observed that the graduate students who have taken the new courses perform just as well or better on the capstone project as the graduate students that took the now eliminated course sequence.

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## AUTHOR BIOGRAPHY

**CHARLES R. STANDRIDGE** is a professor and graduate program director in the School of Engineering, Padnos College of Engineering and Computing, at Grand Valley State University. He has over 30 years of simulation experience in academia and industry. He has performed many simulation applications, developed commercial simulation software, and taught simulation at three universities. His current research interests are in the development of simulation cases management systems (SCMS). He is working with industry on the application of SCMS to lean manufacturing problems particularly inventory control and logistics. His teaching interests are in the concurrent use factory physics, lean manufacturing, and simulation in introductory undergraduate and graduate courses using a case-based approach. He also teaches in the areas of facility layout and material handling as well engineering measurement and data analysis. He has a Ph.D. in Industrial Engineering from Purdue University. His e-mail address is <standric@gvsu.edu>.