An Integrated Approach to Graduate Education in Manufacturing Systems— The U.T. Dallas Model

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ABSTRACT

A graduate program in Manufacturing Systems has been designed by the faculty of the University of Texas at Dallas and a fourteen member industrial advisory committee using a top-down approach. By establishing an independently administered program with it's own faculty, it was possible to design "de-novo" a highly integrated set of new courses in a structured curriculum built around the central theme of the design of computer supported/controlled systems for engineering and manufacturing. There are nine required courses organized under the categories of manufacturing processes, process control, computer systems, product design, manufacturing systems, and business principles. A manufacturing project caps off the curriculum.

I. INTRODUCTION

In January 1987, the Erik Jonsson School of Engineering and Computer Science at The University of Texas at Dallas began planning the implementation of a program in manufacturing systems education with the strong support of local industry and excellent financial resources for program initiation. The general intention was to develop programs that would serve the long range interests of the high technology industries in the Dallas–Fort Worth area, especially in telecommunications, computers, and microelectronics.

The Erik Jonsson School consisted of a well established program in computer science, and a newly initiated program in electrical engineering with an emphasis on telecommunications and microelectronics. There were no programs in industrial engineering or in mechanical engineering to "claim" responsibility for manufacturing, and there were few faculty doing research in areas that fell under the definition of manufacturing that we wished to use. We faced the disadvantage of having essentially no courses on the books or resident faculty resources with which to initiate a manufacturing program. On the other hand, we had no "pieces" of the program that would have led us into a multiple department menu curriculum (two courses from I.E., three from M.E., one from E.E., etc.) that would keep us from developing an independently administered integrated manufacturing program with a faculty of it's own, and we had no preconceived ideas about what constitutes "manufacturing engineering education." Furthermore, the University of Texas at Dallas has a tradition of supporting multidisciplinary programs with a focus on research and graduate instruction.

Our approach, which was consistent with our original goals to serve the long range interests of local industry, was to ask fourteen representatives of primarily local electronics based industries (usually Vice Presidents for Manufacturing) and several consultants to serve on a Manufacturing Systems Advisory Committee to work with the School administration and faculty on a long term basis to define, monitor and evaluate a new Master's level manufacturing curriculum.

The response by industry representatives was enthusiastic and generous. Currently, our committee has industrial representation from Alcatel Network Systems, Convex Computer Corporation, Cyrix Corporation, DSC Communications Corporation, Digital Equipment Corporation, E-Systems, EPI Technologies Inc., IBM, Lennox International Inc., MicroFab Technology, Texas Instruments, and VITEK in addition to representatives from AMK Associates, Collins Associates and The Thomas Group.

II. CURRICULUM GOALS

The basic charge to the committee was to undertake a top-down design of a manufacturing systems curriculum. To initiate this process, each member was asked to reflect on the questions:

- What will your factory look like in the year 2000+?
- What will a manufacturing engineer need to know in order to work effectively in that factory?
- Will the manufacturing engineer be a specialist or a generalist/integrator?

The committee met regularly for a period of approximately one year to study and debate these questions and, although the deliberations of our committee were independent of other groups studying the same basic issue[1-5], the conclusions were remarkably similar. Because of increased global competition, the increasing complexity of the manufacturing environment, and the ever increasing pace of technology change, the committee agreed that the manufacturing engineer of the future needs to be an effective integrator of all the disciplines involved, with the breadth necessary to solve complex technical and managerial problems. These engineers need to be highly productive in design, development, start-up, operation and management of modern manufacturing systems.

The range of challenges facing the manufacturing engineer immediately established that any curriculum had to be broad and multidisciplinary, while still satisfying the requirements for a successful university program that the courses provide a rigorous foundation that lead to, and are stimulated by, a strong manufacturing research program. Indeed, the committee strongly felt that this program should stress student and faculty internships in industry, that research needed to be tied to real manufacturing problems, and that the corporate factory should be the university laboratory.

Some of the manufacturing trends that the UT Dallas Manufacturing Systems program is designed to address are:

λ Faster integration of new technologies into the manufacturing environment. (More change has taken place in the last 5 years than in the previous 25 years)

λ Manufacturing personnel more than ever before need to interact with specialists in many different disciplines.

λ Shorter product life cycles are the driving force for much quicker R&D to manufacturing development cycles and this requires new technologies to break down artificial barriers between design and manufacturing (simultaneous engineering, CIM, etc.).

λ Pressures from the international economy force a much closer and complex tie between marketing, product design and manufacturing than ever before.

λ A more complex, time-dependent character of problem solving is required.

λ Manufacturing elements must be treated as a system and not as a collection of loosely coupled isolated functions(1).

The top-down approach taken by the committee concluded that the curriculum should develop manufacturing engineers who have the following characteristics:

λ A systems orientation.

λ A multidisciplinary approach to solving problems.

λ A decision making approach based on data analysis rather than on intuition.

λ An ability to deal effectively with ambiguity.

λ Good interpersonal skills and a keen awareness of the human element.

λ A good team player.

λ A change agent.

λ Technical depth in one or more key areas.

λ A broad awareness of the business and financial aspects of the manufacturing enterprise.

III. Curriculum Development

The combination of the need for technical depth and broad awareness of many related business and leadership issues provided quite a challenge. We could easily have justified a “two-year” equivalent Master’s program (in excess of 70 semester credit hours), but we chose to restrict ourselves to a normal 36 semester credit hours, “one-year” equivalent program with primary concentration on the technical aspects but with some attention to leadership and business issues.

The guiding principles for curriculum development were:

λ The approach should be revolutionary rather than evolutionary. New courses should be designed rather than relying upon a largely unrelated menu of traditional IE, ME, EE, Materials Science and CS courses.

λ The core curriculum would be highly structured and integrated with each course closely related to, and drawing upon, previous courses.

λ The central technical theme would be the design of computer supported/controlled systems for engineering and manufacturing, and the focus would be on the role of the *computer as an integral part of manufacturing*. Indeed, the role or the use of the computer is to be an important part of every course.

λ A capstone project or thesis would be required, preferably to be accomplished in an industrial setting.

λ The curriculum would be flexible and reflect those elements that are key to the future of manufacturing.

λ The emphasis would be on the rigorous technical aspects of manufacturing, but an effort would be made to integrate important business principles into the curriculum.

An important aid in the committees’ deliberations was the curriculum diagram shown in Figure 1 as developed by Dr. Donald Hayes, a member of the committee. This diagram shows how the various technical and business themes in manufacturing build upon a student’s background in mathematics, physical science, engineering and computer science, and provides a road map for curriculum development.

The wide range of topics to be covered and the desired depth of understanding of the graduates of the program required us to place stringent conditions on student background and preparation, as well as on the pace of study. Every student entering the program is expected to have a bachelor’s degree in an appropriate engineering discipline (usually ME, IE, EE or Chem E), to be currently employed in a manufacturing environment and to have typically 5 years or more experience. This ensures that the students are ready to absorb, understand and apply the material. We also limit the course load to two courses per semester. This results in a two-year program which allows adequate time to explore topics in depth.

These constraints then led to the design of a highly structured set of nine required courses within six major areas plus a manufacturing design project for all students and an opportunity for students to take at least two advanced electives.

The curriculum flow and prerequisite structure is shown in Figure 2. As can be seen, there are five technical areas that lead towards the general theme of computer integrated manufacturing, and culminate in a significant manufacturing project. Although the treatment of business principles is hardly comprehensive, the two required courses stress the concepts of communications, and the business context of manufacturing.

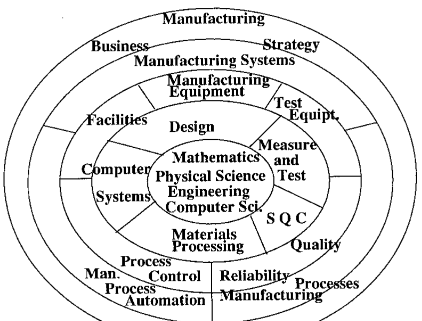

Figure 1. Curriculum development diagram showing the evolution of a manufacturing engineer’s knowledge and responsibility from a sound basic foundation of science, mathematics and engineering fundamentals out to a comprehensive responsibility for manufacturing business strategy.

The required courses in the six areas are:

Manufacturing Processes

MFSC 6301 Materials Processing and Fabrication

Fundamental manufacturing techniques for turning raw materials into finished parts. Machining, welding and joining, bonding, casting and forming, molding, surface treatment. Semiconductor processes, hybrid processes, surface mount technology. Characteristics of processing equipment. Precision techniques.

Required text: Serope Kalpakjian "Manufacturing Engineering and Technology", Addison-Wesley, 1989.

Process Control

MFSC 6310 Mathematical Foundations for Manufacturing

Quantitative methods, especially statistics, for solving problems related to manufacturing. Statistical quality control, design of experiments, control charts, reliability, total quality techniques, statistics in business decisions involving cost, sampling, queuing theory, Markov processes and simulations for modeling and testing manufacturing flow and capacity.

Required texts: Thomas P. Ryan "Statistical Methods for Quality Improvement", Wiley, 1989; William J. Diamond, "Practical Experiment Design for Engineers and Scientists", 2nd Edition, Van Nostrand-Reinhold, 1989.

MFSC 6311 Process Automation and Control

Instrumentation, automation and control of manufacturing processes. Review of SPC, review control theory, process control-manual, process control-automatic, sensors, controllers.

Required texts: John G. Bollinger & Neil A. Duffie "Computer Control of Machines and Processes", Addison-Wesley, 1988.

Computer Systems

MFSC 6320 Computer Systems for Manufacturing

Introduction to Computer Aided Manufacturing. Use of computers, networks and systems to achieve higher levels of automation .

Required text: Mikell P. Groover "Automation, Production Systems and Computer Integrated Manufacturing", Prentice-Hall, 1987.

Product Design

MFSC 6330 Computer Aided Design Systems

Introduction to the use of mechanical CAD systems and factory simulation tools. The use of CAD in the factory.

Required texts: C. D. Pedden, P. E. Shannon and R. P. Sachowski "Introduction to Simulation using SIMAN/CINEMA", McGraw-Hill, 1991; D. Baker and H. Rice "Inside Auto CAD", 6th edition, New Riders Publishing, 1991.

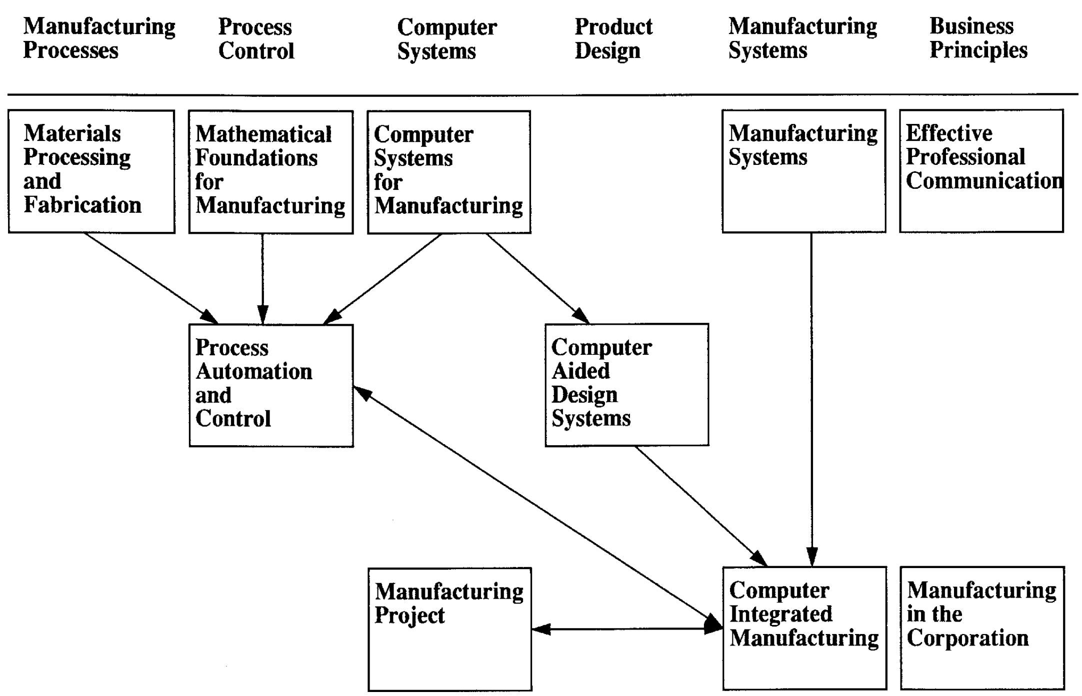

Figure 2. Manufacturing systems course organization, prerequisite structure and course sequencing for required courses. The courses are grouped, as in the text, under six broad categories and are taken in sequence from the top down culminating in the Manufacturing Project and the course on Computer Integrated Manufacturing.

Manufacturing Systems

MFSC 6340 Manufacturing Systems

Overview of manufacturing systems. The evolution of manufacturing in the U.S. is discussed together with the requirements for manufacturing in the coming decades. Topics covered include flexible manufacturing; history of the machine tool, steel, and auto industries; overview of German and Japanese experiences in achieving manufacturing excellence.

Required texts: Nigel Greenwood "Implementing Flexible Manufacturing Systems", Halsted Press, 1988; Philip B. Crosby, "Quality is Free", The Penguin Group, 1980; Donald A. Hicks, "Is New Technology Enough?", American Enterprise Institute for Public Policy Research, 1988.

MFSC 6341 Computer Integrated Manufacturing

Fundamental effect of computers in integrating manufacturing activities and facilities. Artificial intelligence applications. Analysis, modeling and simulation of the integrated manufacturing environment. Synthesis of planning and layout, materials movement and inventory, scheduling, assembly/process organization, inspection and test, robotic systems, on-line quality control and malfunction management. Required text: Paul K. Write and David A. Bourne "Manufacturing Intelligence", Addison-Wesley, 1988.

Business Principles

MFSC 6350 Manufacturing in the Corporation

Integration of modern manufacturing skills into the Corporation. The Malcolm Baldridge Quality Award elements, benchmarking, cycle time reduction.

Required texts: Robert H. Hayes, Steven C. Wheelwright and Kim B. Clark "Dynamic Manufacturing", The Free Press, 1988; Robert C. Camp "Benchmarking", ASQC Quality Press, 1989.

MFSC 6305 Effective Professional Communication

Interpersonal skills and leadership development. Listening, non-verbal communication, meeting organization and elements of management psychology. Effective written and oral communications.

Electives

The most popular electives have been courses specifically designed for this curriculum, such as "Electronic Manufacturing Processes", "New Product Development", "Engineering Economics", "Industry, Technology and Science Policy" and "Engineering Management". A wide range of other courses are available, such as "Computer Vision Systems", "Robotics", "Survey of Artificial Intelligence", "Advanced Engineering Mathematics" and "Semiconductor Processing" for those students interested in more rigorous studies, especially as preparation for research in manufacturing.

IV. Implementation

Our non-traditional approach to a new area of emphasis in engineering education has brought a series of unique challenges.

Students

The maturity of our students (average age of 34) and their industrial experience (exceeding 7 years on the average) are a great asset to the program. As a group, they are serious about improving manufacturing in their organizations. They are able to critically evaluate and in many cases immediately apply the principles they have learned in class. This is of importance in ensuring that students absorb and retain the materials taught. Their own store of experience is, of course, an excellent resource to share with faculty and fellow students. The students have a wide range of backgrounds and career objectives. Currently we have 28 students in the program: 8 mechanical engineers, 7 electrical engineers, 4 industrial engineers, 3 chemical engineers and the remainder with degrees in other fields. It is interesting to note that this program is attractive to women, who constitute 25% of the class. They are typically employed in the semiconductor, telecommunications, electronics equipment manufacturing, consumer electronics, or software industries.

Although diversity of backgrounds and industrial experience is a significant strength to their work environment, we have found that students who have been away from formal studies for several years have often lost proficiency in mathematics, statistics and computer programming, and many do not have any previous background in control systems. Background assessment and allowance for variations in prior academic experience is important.

Industry Involvement

Industry participation has been absolutely critical to our success. The key is extensive and continuing interaction with industry. The interactions come in the following areas:

- The Manufacturing Systems Advisory Committee is a standing committee of the School that meets regularly, to review the status of the program and to provide valuable feedback on effectiveness. This committee is also the primary source of referrals for new students.
- Over half of our courses are taught by Ph. D. level industrial lecturers with extensive industry experience. This ensures that our course offerings keep a "real-world" orientation and applicability.
- Guest lecturers are frequently invited in to present special topics or case studies.
- Tours of manufacturing facilities are regularly used to illustrate the subjects being taught.
- Industries support the use of "real" in-house manufacturing problems for our required student projects.
- Case studies from industry experience are widely used, especially in our courses on "Computer Integrated Manufacturing" and "Process Automation and Control".
- Class room materials developed by industry in areas such as SQC and TQM are valuable teaching aids.
- Industries are generous in making donations of teaching equipment to the university, and/or in allowing use of their facilities for special projects.
- Industries are willing to provide support for faculty to do research on manufacturing problems and encourage close working relationships between faculty and local manufacturing engineers.

λ The National Center for Manufacturing Sciences provides valuable support for the development of this program.

Textbooks and Teaching Materials

Designing new courses "from scratch" has the advantage of consistent intellectual quality and pedagogical coherence, but raises major problems in finding suitable textbooks and teaching materials. Our situation is not the same as is often encountered in newly developing courses, often at the advanced graduate level, where students are comfortable with lecturer's notes, or no notes at all. Since our current students have been out of university for quite some time and suffer some lack of confidence, especially in the areas of mathematics and computer programming, a text book is at least a psychological necessity. The problem is compounded by the relative scarcity of graduate level books with the rigorous quantitative basis that we desire. This often requires significant effort on the part of the faculty to provide supplementary notes and materials to augment the course texts. As alluded to previously, industrially developed materials and case studies are valuable supplements.

Evaluation and Feedback

With a new program, evaluation and feedback is necessary and continuous. We have an active program of consultation among students, faculty, and industrial advisors.

Every six to eight months, the Manufacturing Systems Advisory Committee, the members of which employ most of the current members and graduates of the program, meet to assess the status of the program and provide industrial feedback on the effectiveness of the program. Industrial support remains high, with this committee playing an important role in publicizing the program and recruiting students.

The students are surveyed every semester about their experience with every course—as are the faculty and lecturers—to provide immediate feedback. The satisfaction of the students remains high as evidenced by the fact that many students can immediately apply what they learn in their work environment and also by the fact that at least one half of the new students entering the program were encouraged to do so by current students or recent graduates.

We now have 12 graduates of the program and we are preparing for a systematic survey of the graduates' effectiveness. We keep in close touch with the graduates, the majority of whom have remained in the local environment, and the anecdotal response has been very positive. The most dramatic report we have received is the experience of one graduate who applied the principles of the curriculum to reducing printed circuit board production cycle time from 8 weeks to 1 week in his manufacturing environment.

V. Acknowledgments

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