Curriculum for Integrating Manufacturing Enterprise Decisions (CIMED)

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Abstract

The second year of a three year effort directed toward the development of a research/teaching environment that focuses on integrated manufacturing and enterprise modeling is being pursued through a joint effort by The University of Oklahoma (OU) and Oklahoma State University (OSU). One component of this environment seeks to develop a framework for production management that effectively integrates process planning and other shop floor control functions in a dynamic and stochastic environment. This research is being translated from a methodology domain to an implementation domain to serve two functions: (1) linking the undergraduate courses that comprise the OU-IE curriculum, and (2) providing pluggable modules for other undergraduate programs with a structure unlike the OU-IE curriculum. The software modules being implemented will allow a student to study the role of individual activities and the effect of individual decisions with respect to a global system's performance. Course software is currently developed for five classes and integration of the modules is in progress. Several classes have already begun to use the software at OU. Partners at other universities are also testing the software in their classrooms. A second component of the environment is directed toward (1) the synthesis of a science base for enterprise integration and (2) the development of an advanced modeling environment specifically targeted for discrete-part manufacturing systems. This research is being presented to students through three new graduate courses: (1) Manufacturing Enterprise Integration, (2) Manufacturing Enterprise Modeling, and (3) Simulation and Optimization for On-Line, Real-Time Manufacturing Systems Management. The course sequence is directed toward the development of a unified framework for conceptualizing, designing, modeling, and operating advanced manufacturing systems. A review of the first course (offered Spring 1996) and the second course (offered Spring 1997) are highlighted.

Introduction

Designing and controlling a complete discrete part manufacturing system is among the more complex tasks encountered by engineers in the modern world. A huge, bewildering array of system components of many basic types must be brought together to manufacture an ever-changing mix of products that will satisfy ever-more demanding customers. Companies no longer have the luxury of slowly and deliberately fine-tuning a rigid manufacturing system. In today's competitive world, manufacturing systems must be redesigned and reconfigured continuously. Traditional approaches to manufacturing system design and control are not well equipped to deal with such a dynamic environment.

Although many research results are transferred to the classroom, university curricula are not, in general, adapting to new concepts as rapidly as they should. What is needed is a holistic and global approach that teaches students to integrate rather than fragment. For students to compete in the national and global marketplace, a curriculum which focuses on the parts as well as the whole is required. To realize these potential benefits, developments in manufacturing systems engineering education need to be synthesized into a coherent, unified framework. An entire curriculum must be developed that supports integration of activities and a systems view of manufacturing.

This paper presents the results to date of a combined research and curriculum development (CRCD) effort directed toward realizing a research/teaching environment to focus on integrated manufacturing and enterprise modeling. The work is funded under NSF Grants EEC-9527493 (Oklahoma State University) and EEC-9531194 (The University of Oklahoma). The overall goal of these collaborative efforts is to develop and implement a coherent, unified teaching/research framework that supports a systems view of manufacturing and teaches students to integrate rather fragment when designing, analyzing, and controlling complex manufacturing systems. This joint curriculum development capitalizes on the research accomplishments of two major on-going collaborative research efforts to deliver an integrated set of courses to achieve these goals. A significant element of the post development activities is the leveraging created through cross-university sharing of the developed course materials.

Collaborative Activities

The University of Oklahoma (OU), Oklahoma State University (OSU), and The University of Tulsa (TU) were funded in part by the Oklahoma Center for Integrated Design and Manufacturing (OCIDM) for five years (1989-1994) to conduct research in various areas pertinent to the title of the center. Six faculty members from the Industrial Engineering (IE) program at OU and three faculty members from the Industrial Engineering and Management (IE&M) program at OSU have developed a strong working relationship and have crafted an important niche in Computer Integrated Manufacturing (CIM). As part of these collaborative activities, the programs have fostered research exchanges including joint National Science Foundation (NSF) research projects, faculty and student exchanges, and two-way interactive, compressed digital video courses providing cross-institutional graduate credit.

Integrated Production Management (IPM) Research

A working sub-group of faculty from OU (B. Foote, S. Pulat, S. Raman and A. Badiru) and OSU (M. Kamath) were funded under a three year research grant funded by the Division of Design, Manufacture and Industrial Innovation at the NSF to conduct research towards the development of an integrated production management environment. The research entails a multi-disciplinary approach for CIM in the modern factory. Instead of focusing on the fragments of the CIM structure, this research concentrates on the integration itself.

The main aim of this research is to develop a 'maximal' production management methodology. This methodology takes advantage of the major sources of flexibility and response available to a manager such as selecting lot sizes, process plans, processes to create features, sequencing of processes, inventory created, shortage accepted or subcontract awarded. The methodology will apply to a hybrid assembly job shop that manufactures components some of which go to an assembly line (Foote et al, 1993;1995). Since this is a very generalized scenario, most other factory environments can be easily handled.

The individual data fields (time standards, process plans, holding costs, reliability and defect rate data, etc.) are limited to those currently available in actual manufacturing systems known and explored by researchers. However, the individual choices must be properly coordinated since optimizing an individual variable such as lot size may overload a bottleneck resource, optimizing flow time by the shortest processing time may increase tardiness and again overload a temporary bottleneck. Hence, the key problem deals with the development of an overall framework for production management that effectively integrates the process planning and other shop floor control functions in a dynamic and random environment. A pyramid shaped hierarchical decision making structure is under development where the top level involves long range decisions made at a low frequency, and the lowest level involves short term decisions (such as daily production plans) which are made most frequently. Each level contains an appropriate version of fast simulation/ queueing module, process planning module, optimization module and scheduling module. An intelligent controller can provide the interaction between the database and the specific modules of each level and determines the next module to be invoked in the process. The research activity is being structured and translated from a research domain to an implementation domain in the current project. The software implementation required for the transfer of these methodologies to classrooms and the curricula in general is under development. This research is also supplemented by other recent grants obtained from NSF-DMII (by the various researchers involved in the present activity) in the areas of factory facility planning, advanced modeling environments, queueing theory and state space-expert system hybrid model for design.

Integrated Enterprise Modeling Research

The state-of-the-art in manufacturing system design is to initially employ analytical methods (such as queueing network models) that provide "rough cut" estimates of system performance to assist in the determination of candidate designs. Discrete event simulation models are then used to include more system details and provide detailed performance measures needed for the final selection phase. In this approach the total system behavior is modeled only in an aggregate and approximate manner. Many critical elements of the system, such as information elements and decision/control elements, are not modeled explicitly at the system design stage. This practice can be to a great extent attributed to the inadequacy of today's modeling and simulation tools and environments to represent and manipulate details of complete system descriptions The lack of comprehensive modeling environments, that is, those that can handle complete system descriptions and permit modeling across several problem domains using multiple tools, makes it extremely difficult to create robust system designs or to quickly change existing systems to remain competitive. While working in this area over the past seven years, a working sub-group of faculty from OSU and OU have become convinced that the object-oriented paradigm best supports enterprise modeling at the level and completeness required. Significant progress has been made as part of the research agenda of an on-going research program in the Center for CIM at OSU. The research is directed toward (1) the synthesis of a science base for enterprise integration and (2) the development of an advanced object-oriented modeling environment specifically targeted for discrete-part manufacturing systems. Since the project's inception in 1985, the research team has made several major breakthroughs in modeling methodologies that are attracting attention in the research community both nationally and internationally. The seminal paper on this work, "The Modeling of Integrated Manufacturing Systems Using an Object-Oriented Approach" (Mize et al., 1992) was recognized as the Outstanding Technical Paper for 1992 by the Institute of Industrial Engineers. The continuing research in this area is currently supported by funding from the AT&T Foundation (Manufacturing Technology Grants Program), The Oklahoma Center for Integrated Design and Manufacturing (OCIDM), and an NSF Integration Engineering grant.

The research work on this project has been largely conceptual and exploratory. Consequently, it is just now reaching the point where widespread dissemination into engineering education and practice is on the horizon. In the past, technology transfer has occurred through publication in journals and presentations at national and international conferences. While we take pride in our past accomplishments in basic research, we will not consider our efforts complete until we see large number of practicing engineers routinely using our modeling environment to assist in their efforts to conceptualize, design, evaluate, implement, and manage the integrated manufacturing systems that will be required for a firm to be competitive in the 21st century. To accomplish this requires students with the requisite fundamental knowledge. The proposed curriculum development addresses this need.

Undergraduate Curriculum for CIMED

The on-going integrated production management research is structured and translated from a methodology domain to an implementation domain whereby a *multi-modular* integrated software system for linking courses at various levels is under development using the research methodologies. The curriculum development effort is to be two-fold:

- Develop a strong thread for integrating existing manufacturing/production/modeling courses in the curriculum at OU which is adaptable to other programs with a similar structure. The proof of concept of this effort is being implemented at OU.
- Develop pluggable modules for use in integrating manufacturing courses within curricula that are structured in other ways. The proof of concept of this effort is being implemented at OSU, Wichita State University (WSU) and Kansas State University (KSU).

A software environment for instruction is under development, that will be maintained as the main vehicle for research deployment. The development of other forums and media to encourage student participation and classroom implementation is also investigated. Thus the research deployment tools will include interactive software modules, manuals, methodologies and presentations. Instead of focusing purely on the traditional method of instructor dissemination, *a discovery-oriented self-teaching curriculum* is being developed that exchanges methodologies, ideas and implementations pertaining to integrated manufacturing. The participants of this effort (OU and OSU) will serve as the initial test sites for “modularization” and full program implementation. Other schools, such as WSU and KSU have also volunteered to serve as beta-sites for this program.

The integrated computerized framework will contain all modules pertaining to the integrated production management research. However, the students at any and all levels can gain from the research methodologies by a cooperative and interactive plan. The interactive program will allow each set of students at a certain knowledge/skill level to test their ideas and knowledge interactively within an existing framework. The validity of their plans and decisions are evaluated (for a given set of inputs and expected outputs) with respect to the current best plans generated by preprogrammed research methodology. Manuals and instruction booklets are developed to provide the student with easy means of interaction with the software. A higher level student will have the opportunity to extend and reevaluate his/her plans, based on new knowledge gained. Thus, a chance is provided to continuously develop one's ideas to improve the system's performance. The game-oriented nature of learning also provides an easy and 'fun' atmosphere to learn. Since this participation is being implicitly and inherently embedded into existing courses, significant additional effort on the students is not demanded.

Each course teaches all the relevant facts and fundamentals, that otherwise comprised the traditional offering. Additionally, the course provides the innovations developed through a dissemination plan that will be a combination of senior/ graduate students and professors instructing students on the usage of the software system in a way consistent with their knowledge level. Current manuals have been developed for classes based on the student's knowledge level. The students will work individually and in teams to develop the module pertinent to a class and will have an opportunity to test it within the overall factory framework model. Then they will get an opportunity to then analyze the efficiency of their plans. Each class will be kept modular and learning will be stepwise.

According to our plan, classes are classified into three categories: methodology discipline, activity discipline, and integration discipline. The methodology discipline includes four courses: Deterministic Operations Research (OR), Stochastic OR, Microcomputer Applications, and Simulation. The activity discipline includes four courses: Design and Manufacturing Processes, Analysis for Manufacturing Processes, Production Control, and Facilities Design.
Students know the concept of process planning and can implement a plan at a primitive level (without analysis) by the end of the Design and Manufacturing Processes course. They test the efficiency of their plan at that level with respect to a preprogrammed research-generated global factory plan. The best plan is developed drawing on recent research conducted by the IPM team. The reader is referred to Mani (1996) for the methodologies and software development in process plan optimization. At the end of the Analysis for Manufacturing Processes course they learn manufacturing tolerance concepts, fixturing principles, machining/non-machining/set-up/down time calculations and manufacturing cost analysis and at this stage will be able to reevaluate their previous plan and observe the efficiency improvement of the system based on their new knowledge. This will provide them with a quantitative means to examine the gain in their knowledge. Similarly, lot sizing, sequencing and forecasting are learnt in Production Control while facilities layout and factory design are covered in Facilities Design. At each stage of this four course sequence, they are learning more system concepts and at the end of the four courses

they will fully understand how the system integrates with the process. Thus, instead of waiting for the student to assimilate the knowledge gained in these four classes themselves, an orderly integrated software teaches integration of courses while teaching integration of manufacturing. During this process, the individual role of each class is fully realized. Various metrics are being examined such as process plan generation and machine layout. The course software for the four classes are complete and software has already been tested in three classes. The feedback obtained will be used to fine-tune the system for future offerings.

Simultaneously they are taking the methodology sequence courses and Deterministic Operations Research where they will be able to develop mathematical programs to model certain metrics within the production system. Good success was experienced in implementation in the last offering of the class. The students can simulate solutions for different configurations and compare with the deterministic case in Stochastic Operations Research. Overall system concepts, and principles of expert systems and object-oriented programming are explored at two levels; Microcomputer Applications and Simulation.

One option of the integration discipline includes the three newly proposed graduate courses in CIM developed under the graduate curriculum component of CIMED. OU students are taking these courses through compressed video and other advanced distance learning methods from OSU. A second option in factory training is under investigation. The advantage of the integration discipline courses is that the students at senior undergraduate/graduate levels, who previously have not participated in the CIMED plan can participate in it.

The undergraduate curriculum will nicely integrate into the initial test-bed (IE curriculum at OU) without drastic changes. The undergraduate course sequence consists of seven existing courses and four electives, which does not alter the existing total credit hour requirements. The Engineering Design/Engineering Science balance, as per current ABET requirements will also not be significantly altered. Other issues include:

1. CIMED is the only one of its type in IE or Manufacturing Engineering institutions in the country!
2. A forum for lifelong education for retraining ex-students to meet with current challenges is also proposed.
3. Four classes within the activity and methodology sequences have already been tested with the developed software. Two others will be tested in Spring semester of 1997. The program modification , integration of modules and the class material for two other courses are under development. One of the three integration courses was offered in the last year and the two others are expected to be offered in Spring semesters of 1997 and 1998.

Graduate Curriculum for CIMED

The graduate curriculum development effort within CIMED is directed toward contributing to the development of a unified framework for conceptualizing, designing, modeling, and operating advanced manufacturing systems. Specifically, three new graduate level courses are being developed, one during each year of the funding: (1) Manufacturing Systems Integration, (2) Manufacturing Enterprise Modeling, and (3) Simulation and Optimization for on-line, real-time

Manufacturing Systems Management. The three course sequence is designed to first introduce concepts, then discuss modeling approaches and methodologies, and then present utilization issues and value-adding implementation opportunities. Each of the three of the courses will directly benefit from the on-going research conducted within the OSU Center for CIM as well as the joint production management research conducted in collaboration with OU. These courses will also be offered to senior undergraduate students with appropriate backgrounds.

During the first year of the three year project, the course Manufacturing Systems Integration was designed, developed and offered. The course focused on advancing a unified framework for conceptualizing integrated manufacturing systems. It built upon recent developments in computer and communications technologies and conceptual breakthroughs regarding the nature and behavior of integrated enterprises. The course drew heavily from time-tested, experience based material which had previously been presented through System Integration workshops sponsored by the Institute of Industrial Engineers. A course outline is shown below in Figure 1.

Manufacturing Systems Integration Course Outline

Introduction
    Manufacturing Megatrends
    History of CIM Systems
    Driving Forces of Change
Consideration of Strategic Issues
    Factory of the Future
    Competing through Manufacturing
    The Integrated Enterprise
    Comprehensive Planning Process
Foundations of Integration
    The Role of General Systems Theory
    Enterprise Rationalization
    Definitions of CIM
    Fundamentals of Integration
Enabling Technologies
    Data Communications
    Planning Tools: IDEF0, IDEFTD
Integration Implementation
    Implementaion Guidelines: Case Example
    Managing Change
    Managing Discrete Projects within an Integration
    Initiative
 	
Student Project Presentations

Figure 1 - Manufacturing Systems Integration Course Outlines

The course Manufacturing Enterprise Modeling will be offered during the Spring semester of 1997. It will capitalize on recently developed concepts in data modeling and information engineering. The course will build upon a conceptual understanding of an integrated enterprise by exploring modeling tools and methodologies which have been developed for designing and reconfiguring the various sub-systems of a manufacturing enterprise. The course is designed to be a broad overview of several prominent enterprise modeling tools, methods, and architectures including the CIM-OSA method and architecture, the IEM method, IDEF modeling tools, and object-oriented (OO) approaches. Other topics to be covered include entity relationship modeling and structured systems analysis and design methodology (SSADM). In addition to discussing the salient features of the various tools, methods, and architectures, their role and scope in enterprise modeling will also be presented. A tentative outline of this course is shown in column 1 of Figure 2.

The third course that we will develop, Simulation and Optimization for On-Line, Real-Time Manufacturing Systems Management, will be addressed to the various operations managers of a manufacturing firm. There have been some recent theoretical developments upon which this course will capitalize. Only in the very recent past have we been able to even conceive of this type of factory management capability. Conceptually, a detailed model of a manufacturing system is kept current and is available for instantaneous usage at any time. The model would be connected directly to the data bases of the factory, and driven by actual data. Modularized decision elements will be specified within a hierarchical framework. From any decision point in the factory, the simulator will assist decision makers in looking at upstream work centers to see what work load is imminent, and at downstream work centers to ascertain condition (i.e., machine breakdowns, long waiting lines, etc.) that will affect material flow. With this important information, a decision maker, with the aid of the simulator, can assess the impact of alternative decisions upon the total system. Sub-optimal local decisions (relative to the entire system) can be avoided in this manner. A tentative outline for this course is shown in column 2 of Figure 2.

Manufacturing Enterprise Modeling	Simulation and Optimization for On-Line, Real-Time Mfg. System Management
Introduction to Enterprise Modeling	A New Modeling Paradigm
Definitions	Database Connectivity Issues
Purpose & Means of Enterprise Modeling	"Plug Compatible" Decision/Control Modules
Information Engineering and Data Modeling	Avoiding Sub-Optimal Decisions
Entity Relationship Modeling	Transaction Triggered Events
SSADM	Order Accum. & Release Rules
Information Engineering Methodology	Capacity Management
CASE Tools	The OSU Advanced Modeling Environment
Overview of Tools, Methods, and Architectures	Mfg. Modeling Workbench
CIM-OSA	Dynamic Optimization Strategies
IEM Method	The Learning Organization
IDEF Methods and Tools	
Object Orienter Approaches	
Toronto Virtual Enterprise	
Purdue Enterprise Reference Architecture	
Current Issues and Future Directions	

Figure 2 - Tentative Graduate Course Outlines

The plan for implementation of the CIMED graduate courses is based on three one-year cycles; one course per year. The first half of each of the three years is directed towards the development a unified set of teaching materials. This effort involves both the PIs and Co-PIs as well as graduate students participating in the research. During the second half of each year one of the PIs or Co-PIs present the developed course to OSU and OU graduate students via the distance learning facilities housed on the OSU campus. The distance learning facility located on the OSU campus is a world-class distance education studio capable of digital, two-way interactive, compressed video transmission via fiber optic lines or satellite. This facility is currently used heavily to support OSU's participation in The National Technological University (NTU). Through this vehicle, the proposed courses could be offered to any academic institution or industrial site capable of receiving such broadcasts.

Program Assessment

Regular meetings are conducted throughout the year by the two participating schools, including Co-PIs and graduate assistants to maintain seamless integration of the graduate (Oklahoma State University) and undergraduate plans (University of Oklahoma). An assessment and advisory committee board meeting was conducted in Summer 1996. The assessment and advisory group consisted of one OU Chemical Engineering faculty member, two chairs of IE Programs (Wichita State, Kansas State) and three industry participants (Oklahoma Alliance, York International and Entec Corporation). Several other OU faculty were invited to participate (and attended) as special guests including the Provost of the university and two education-related professors. The meeting lasted a full day, with morning presentations by PIs Raman and Pratt followed by laboratory software demonstrations in the afternoon. As part of the assessment, one of the course module software has been given to the two IE department heads for beta-testing and feedback. Two of the industry participants have been requested to make a needs document of requirements for incoming engineers into industry and their on-work training and the relevance of the developed software as an educational tool to meet the demands of the industry. The results are being awaited. The feedback will be used in the developing project.

Summary

OU and OSU are collaborating to develop a unified program for teaching integrated manufacturing to students. OU is leading the undergraduate curriculum development effort based on the deployment of recent research results obtained from an on-going integrated production management project. Drawing on the results of an advanced modeling project, OSU is leading the development of a graduate curriculum in integrated manufacturing. Software for four courses of a possible eight have been written and tested in the respective classes with two others proposed in Spring 1997. A three-course integration sequence borrows from the graduate courses developed at OSU and offered via advanced distance leaning to OU. The first of these courses has already been offered and a second is scheduled for Spring 1997. Excellent participation by industry and other schools has also been made possible through an assessment and dissemination committee. It is believed that the present activity for teaching integration to undergraduate and graduate students is unique and is of very high significance to the US industry.

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