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A Model to Develop and Incorporate a Computer Integrated Manufacturing Laboratory into an Engineering Curriculum

DON BYRKETT and OSAMA ETTOUNEY
Department of Manufacturing Engineering, Miami University, Oxford OH 45056, USA

In this paper, a model to develop and incorporate a computer-integrated manufacturing (CIM) laboratory into an engineering curriculum is discussed. The model emphasizes the importance of the evolutionary process incorporated in such an experience rather than the purchasing of a turn-key commercial system. Also, the model stresses the essential role of interdisciplinary work in creating and directing such an environment rather than the one disciplinary approach. The model discussed in this paper reflects our experience at the Manufacturing Engineering Department, Miami University, since 1986 of the development and use of such a CIM laboratory. The results sparked a gradual increase in the use of computing throughout the engineering curriculum. In addition, this laboratory has been a focal point for involving students from systems analysis in manufacturing software development and students from psychology in manufacturing ergonomic studies.

INTRODUCTION

IN 1986, the Manufacturing Engineering Department at Miami University began the development of a computer integrated manufacturing (CIM) laboratory. The faculty in this department recognized the importance of preparing manufacturing engineers to work with computers and automated manufacturing technologies. This laboratory was developed to prepare students to deal with these technologies, as well as to provide an environment for the faculty themselves to stay abreast of new technology. This paper describes the development of this laboratory over a 9-year period, and how the curriculum has been modified to take advantage of the laboratory.

Specifically, the goals of the laboratory are to provide a state of the art facility to allow:

- students to be able to integrate computers with manufacturing operations;
- students to carry out independent and group projects to enhance the capabilities of the laboratory;
- students from various disciplines to carry out interdisciplinary research projects;
- expanded coverage of CIM concepts throughout the curriculum (freshman to senior courses);
- faculty to develop their expertise in CIM and to carry out research projects;
- industry to use for continuing education and training courses; and
- industry to collaborate with faculty on research projects.

So far, the faculty have been very successful at achieving the first five goals, but have only limited success with the last two goals.

It should be mentioned that when we first began development of the CIM laboratory with a grant from the Westinghouse Educational Foundation, we considered purchasing turn-key type systems for the students to use. However, since the goal of our laboratory is not to get a system up and running, but to provide educational opportunities for students and faculty, we decided to pursue an alternate option. We felt that we could better achieve our goal by purchasing separate components and allowing students and faculty to perform the integration and development activities. All of the laboratory development described later has been brought about by students in laboratory classes and senior design projects, by faculty in developing laboratory activities, and by our laboratory technician under the direction of students and/or faculty.

OVERVIEW OF THE CURRENT CIM LABORATORY

The CIM laboratory is designed to provide a laboratory environment that simulates the functions and processes carried out in a typical manufacturing enterprise. Specifically, the following five business functions are supported in the laboratory: ergonomic and material testing; product design;

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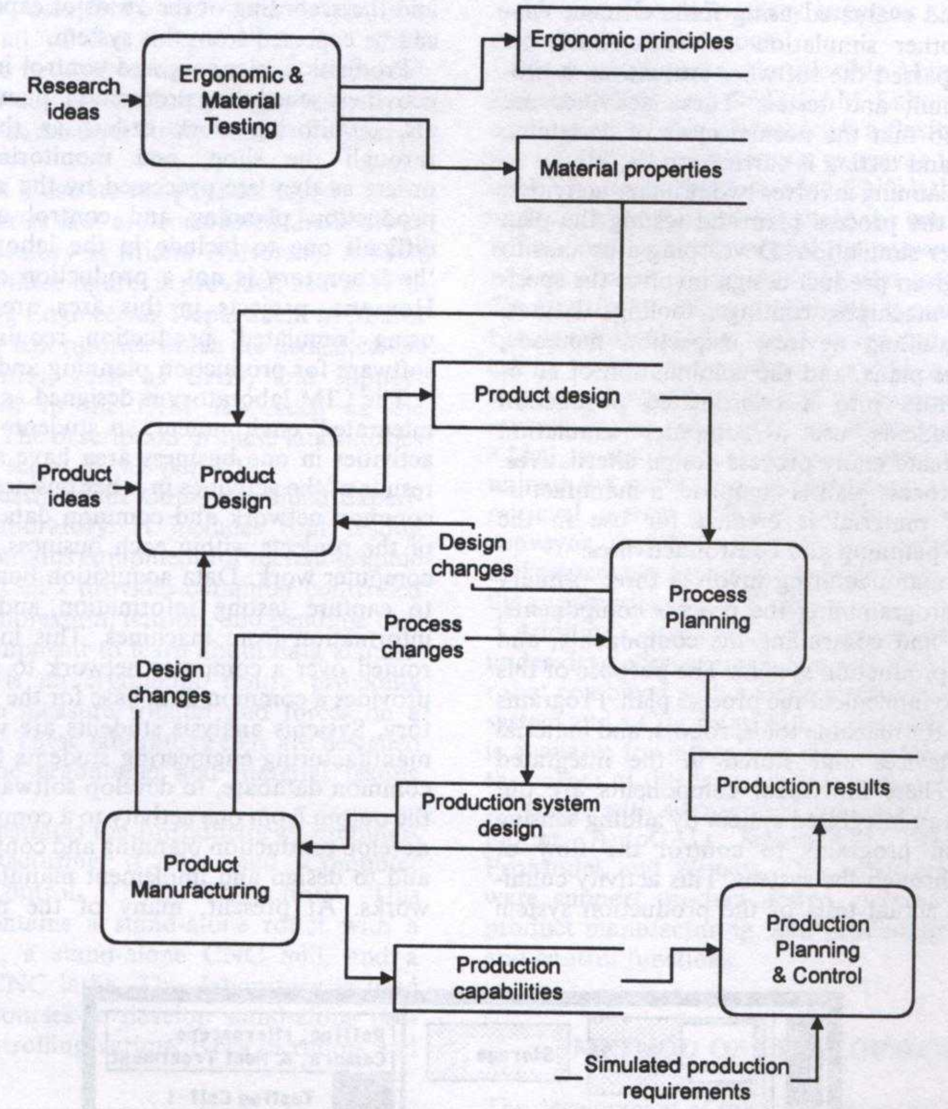

Fig. 1. A data-flow diagram that illustrates the relationships among the five business functions and the databases that will be integrated in the CIM laboratory environment.

process planning; product manufacturing; and production planning and control. Each of these functions is described in detail in the following paragraphs, and Fig. 1 contains a data-flow diagram to illustrate the relationships between these five functions and the databases that will be integrated in the CIM laboratory environment. The business functions are represented as rounded rectangles, the data inputs and outputs as arrows, and the major components of an integrated database as square rectangles.

These business functions are similar to those contained in the Computer and Automated Systems Association/Society of Manufacturing Engineers (CASA/SME) CIM wheel [1], but have been modified to reflect the educational needs of the students, the expertise of the faculty, and the ability to perform the activity in a laboratory environment. For example, marketing activities are not included since they are not appropriate for a laboratory environment. In the laboratory, research and product ideas originate from the faculty to form student projects or research projects. Students and faculty develop these ideas into product designs, process plans, and automated production systems.

Ergonomic and material testing involves two primary activities: conducting ergonomic experiments and testing materials properties. The results of these activities will eventually be stored in an integrated database and will be available for product design and process planning activities. Ergonomic experiments are conducted jointly by faculty and students involved with the Center for Ergonomic Research in the Psychology Department.

Product design involves three primary activities: designing a product, analysing the design, and building a prototype to test the design. The first two activities are software oriented. Students use computer aided design (CAD) software to develop a preliminary product design. Then, the design is modelled and evaluated using finite element analysis and other simulation software. Once the design has passed the software evaluation, a prototype is built and tested. These activities are integrated so that the normal cycle of designing, modelling, and testing is carried out easily.

Process planning involves two primary activities: developing the process plan and testing the plan via computer simulation. Developing a process to produce a given product design involves the specification of machines, routings, tooling, fixtures, material handling devices, inspection methods, maintenance plans, and the combination of all of these activities into a coordinated production system. Students use a computer simulation model to create many process design alternatives. Once the process plan is complete, a manufacturing bill of material is created for use in the production planning and control activities.

Product manufacturing involves three primary activities: programming the process components, integrating and controlling the components, and testing the production system. The purpose of this activity is to implement the process plan. Programs are written for machine tools, robots, and material handling devices and stored in the integrated database. These individual components are put together in an integrated system by adding sensing devices and programs to control the flow of materials through the system. This activity culminates with actual tests of the production system and the recording of the kinds of capabilities that can be expected from this system.

Production planning and control involves four activities: scheduling production, planning materials, monitoring work orders as they progress through the shop, and monitoring purchase orders as they are processed by the vendors. The production planning and control activity is a difficult one to include in the laboratory, since the laboratory is not a production environment. However, projects in this area are undertaken using 'simulated' production requirements and software for production planning and control.

The CIM laboratory is designed as a 'computer integrated' environment, so students working on activities in one business area have access to the results of the activities in other business areas via a common network and common data base. Many of the projects within each business area involve computer work. Data acquisition boards are used to capture testing information and production information from machines. This information is routed over a computer network to a server that provides a common data base for the CIM laboratory. Systems analysis students are working with manufacturing engineering students to design the common database, to develop software to convert the output from one activity to a common form, to develop production planning and control software, and to design and implement manufacturing networks. At present, many of the machines are

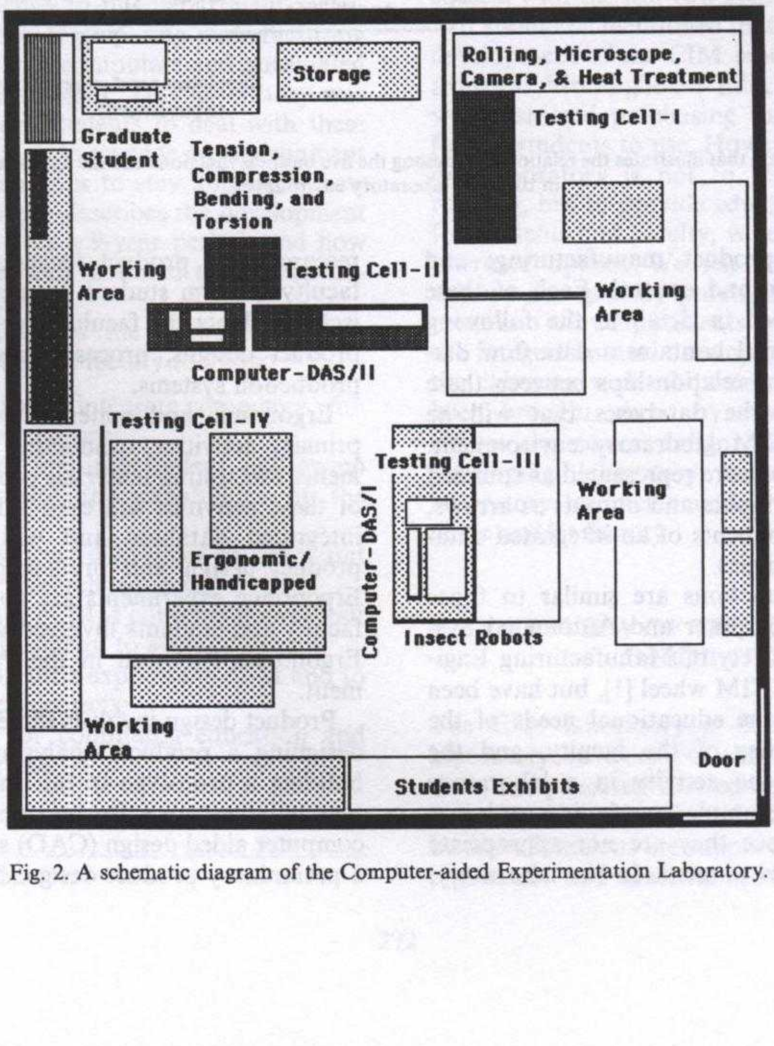

Fig. 2. A schematic diagram of the Computer-aided Experimentation Laboratory.

connected to computers via data acquisition boards and all of the computers in the CIM laboratory are networked together and connected to the School of Applied Science network server. The common database is still in the early stages of development.

Figures 2–4 illustrate the physical layout of the three laboratories that are considered the heart of the CIM laboratory at Miami University. A brief description of these figures is provided below. (The Manufacturing Engineering Department at Miami has four other laboratories which are dedicated for specific activities, such as CAD, and support students' work in the CIM lab, such as the Model Shop. The description of these laboratories is beyond the scope of this paper.)

Figure 2 illustrates the Computer-aided Experimentation Laboratory. It includes four testing cells. Cell 1 contains equipment for metallographic examination. Cell 2 provides computer controlled testing for compression, tension, and bending. Cell 3 contains equipment to learn about data acquisition. Cell 4 is an ergonomic centre providing capabilities to measure friction and forces on a seated person. These laboratory cells are designed to support the ergonomic and material testing functions.

Figure 3 illustrates the Introductory Computer-aided Manufacturing (CAM) and Computer Numerical Control (CNC) Laboratory. This laboratory contains a stand-alone robot with a vision system, a stand-alone CNC mill, and a stand-alone CNC lathe. This laboratory is used in the early courses to develop stand-alone programs for controlling various types of robots and machines. This laboratory supports the product manufacturing functions.

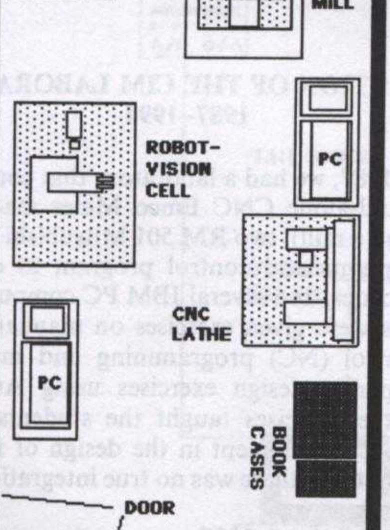

Fig. 3. A schematic diagram of the Introductory Computer-aided Manufacturing and Computer-Numerical Control Laboratory.

Figure 4 illustrates the Flexible Manufacturing System (FMS) and CAD/CAM Laboratory. The centre-piece of this laboratory is a flexible machining cell (FMS), which uses a conveyor to link four cells. The oldest cell includes a CNC lathe, camera, and robot. As parts move along the conveyor on a pallet, sensing devices signal the conveyor to stop so that the robot can load the part into the lathe for machining. When machining is complete, the part is returned to the pallet on the conveyor. This cell is under the control of a PC with special software designed to control all components and sensors in the cell. Later, an additional cell was added to the FMS to allow a robot to load or unload the parts from an automatic storage and retrieval system (AS/RS) to the pallet on the conveyor. A CNC mill with a supporting robot and camera are envisioned as future cells to expand the capabilities of the FMS.

Additional areas in this lab, which are currently under development, include a cell with a SCARA robot combined with a vibratory feeder and vision system and a Cincinnati Milacron controller which is available for integration into the laboratory. In the corner of this laboratory is a modular computer centre with six personal computers, printers, a plotter, AutoCAD, SmartCAM, COSMOS/M, ProModel, and Witness. This hardware and software support product design, process planning, product manufacturing, and production planning and control functions.

METHOD OF DEVELOPMENT

The development of the CIM laboratory started in the summer of 1987, when the Department of Manufacturing Engineering applied for and received a $45,000 grant from the Westinghouse Educational Foundation. This 3-year grant was used to develop an automated manufacturing laboratory for teaching undergraduate students about modern technology and supported faculty research and development as well. The initial equipment for the laboratory was supplied through a $25,000 grant from SME and another $25,000 from Miami University. Four faculty members (two mechanical and two electrical engineers), were initially involved in the CIM laboratory development. This involved enhancing faculty expertise in this area, such as flexible-manufacturing systems; researching available commercial systems on the market, and developing students projects through a capstone course [2].

After we conducted literature research, visited industrial facilities and academic institutions, and reviewed several commercial, turn-key, automated manufacturing models available for educational purposes [3], we decided to develop our own model in order to give our students and faculty hands-on experience and expertise in this field.

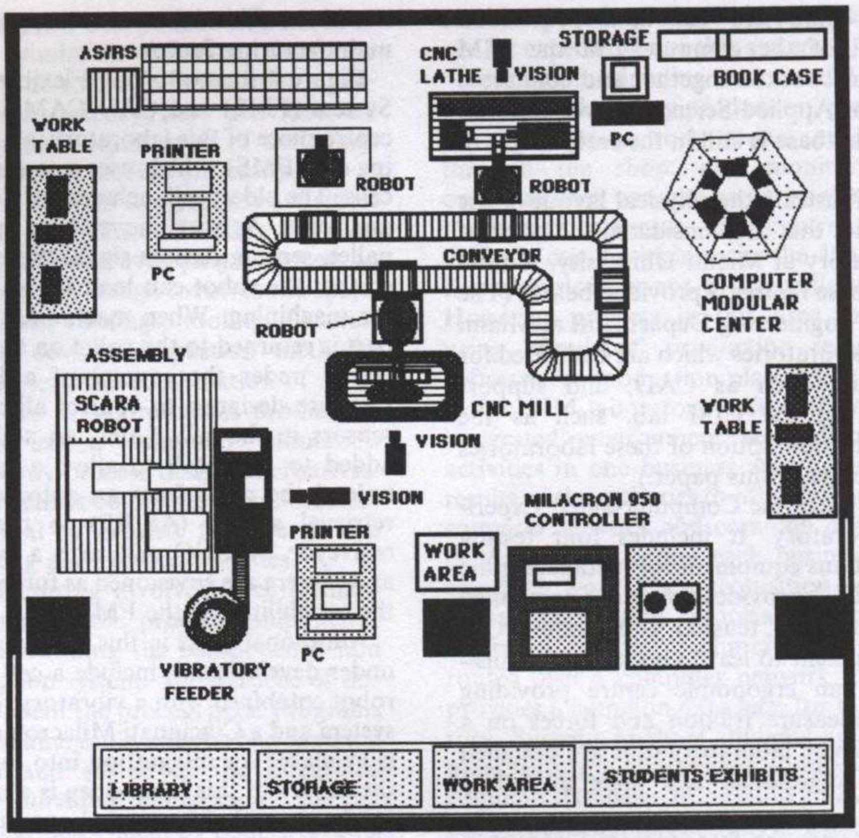

Fig. 4. A schematic diagram of the Flexible-Manufacturing System and CAD/CAM Laboratory.

Developing our own model allowed us to design a more flexible system that fit our needs and permitted for future expansion. None of the existing systems provided this opportunity. In addition, since the least expensive system cost over $100,000, cost was another important factor:

The laboratory was designed and implemented using senior design projects, faculty summer work, and our laboratory technician [2]. The design was based on the hardware integration approach described by Kuttner [4]. The integration approach required the assembly of building blocks called 'robot cells' or 'islands of automation' into the manufacturing configuration. Each cell consists of a machine tool, one or more robots, inspection devices, and a 'bus interface unit' for connecting to the rest of the network. Advantages of this approach included rapid implementation, incremental growth, and flexibility.

The concept of the CIM laboratory was not fully realized until 1992. Between 1987 and 1992, the laboratory went through several evolutions that took it from a simple one machining cell to the full fledged laboratory discussed earlier. This experience was very educational and quite economical for us. Although the pace of development, at times, was slow, it enabled us to create a laboratory developed primarily by the students and for all students. One of the primary lessons we would like to convey to readers is that one cannot develop a true CIM laboratory experience overnight. It is essential to think about taking small steady steps that integrate the laboratory slowly into the curriculum, as well as developing the appropriate expertise in the process. The next section provides a discussion of the evolution that helped shape the current CIM laboratory. We will also discuss several, more recent developments in the laboratory; therefore our discussion will extend up till 1994.

EVOLUTION OF THE CIM LABORATORY: 1987–1994

Before 1987, we had a laboratory that consisted of two stand-alone CNC Emco Maier machines (a lathe and a mill), two RM 501 Mitsubishi robots, a manual numerical control program to create M and G codes, and several IBM PC computers. The students were given exercises on manual, numerical-control (NC) programming and machining, and separate design exercises using AutoCAD. While the exercises taught the students how to utilize such equipment in the design of manufacturing systems, there was no true integration in this experience.

In the fall of 1987, we used senior design projects, capstone course to start developing the laboratory (for more details, see [2, 5–7]). Two groups of senior students worked on two problems that dealt with product design and manufacturing.

The first problem was to develop a stand-alone machining cell, that consisted of a PC computer, an RM-501 Mitsubishi robot, and an Emco Maier compact-5 CNC lathe. The computer program was written in BASIC and utilized the robot controller to manipulate the different functions of the cell. Also, the CNC program was developed and downloaded manually to the machine. The second problem was to develop a CAD/CAM workstation, which linked CAD software, AutoCAD, to a commercial finite-element program, MscPal2, and to other computer software for failure analysis and gear design [5].

In the fall of 1988, we utilized more senior projects to expand the capabilities of the machining cell and the CAD/CAM station by developing a new material handling system and a computer-aided material testing cell [2, 6–7]. Two groups of students worked on the design and implementation of the dedicated, flexible-machining cell (FMC) shown in Fig. 5 (see also Fig. 4), and one group worked on the testing centre, shown in Fig. 6.

To implement a new FMC, students added the following equipment to the first FMC design: a Span Tech XL Loop conveyor belt; an electronic units (photo-cells and limit switches); a pneumatic system; and other components.

The new design worked as follows [2]: when the conveyor's motor is turned on, the pallets move with the belt. The photo-cell detects the workpiece and sends a signal to the controller that turns on the guard's pneumatics. These guards are attached to the conveyor system and allow only one pallet to pass to the loading station. There, a limit-switch detects the carrier and sends a signal to the controller that turns on another guard's pneumatics to stop the pallet. Also, the pneumatics are connected to four cylinders that raise the carrier off the belt for the robot to pick up the workpiece. The robot loads the workpiece into the CNC lathe, and a signal from the controller triggers the pneumatic-precision chuck to close and hold the part securely in place. The robot arm retracts and machining starts while the camera monitors the operation. After machining is completed, the robot locates the part and loads it onto the carrier. Finally, the guards retract and the carrier moves to the next station while a new carrier moves to the machining station.

To achieve the above operation, computer programs are used for the CNC lathe, the robot, the electronics, and the pneumatics. A master program, written in BASIC, connects the robot controller (which acts like a programmable controller) to the photo cell, the limit switches and the pneumatics. This program calls other sub-pro-

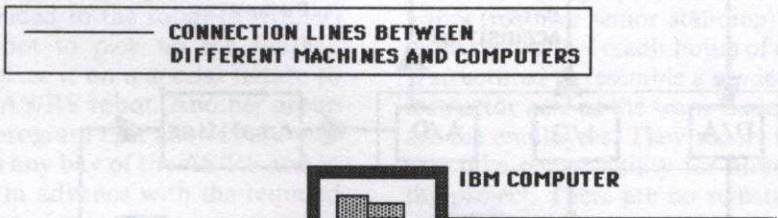

Fig. 5. A schematic diagram of the flexible-machining cell.

grams, written in ASSEMBLY, that control the CNC operation, the robot and the chuck movements.

The testing centre consisted of a computer-controlled testing machine that performs three operations (see Fig. 6): tension, compression, and bending (see [6, 7] for more information). To develop this machine, a manual Baldwin testing machine was converted into a computer-controlled one by equipping the machine with digital equipment and interfacing it with a computer. The instrumentation used was as follows: Dillon 100,000 lb load cell for force measurement; Nikon encoder for displacement measurement; DIGITAL read outs; Moog servo-valve for speed control; MicronEye vision system for shape measurements; data translation, data acquisition system; and an IBM AT computer.

In 1989, we utilized SmartCAM (computer-simulation, commercial software [8]) with the existing AutoCAD software to conduct true CAD/CAM exercises. This new capability improved the types of design projects and exercises that we could conduct in our laboratory. Furthermore, this allowed the students to utilize more modern technologies, as well as get closer to the spirit of CIM, which integrates the activities of CAD and CAM [5].

In 1990–1991, a local-area network to link all the computers was developed by two graduate students from the Systems Analysis Program. An Ethernet-based network was selected for the laboratory for compatibility purposes with other existing networks. This network's file server is an IBM RS/6000, which runs the AIX operating system. The workstations and cell controllers are IBM compatible PCs running MS-DOS. The network software is Network File System (NFS), which is implemented using the TCP/IP Protocol suite [8]. To ensure flexibility in re-organizing the machines and cells in the laboratory floor, an Ethernet twisted pair hub, which provides a star topology, was chosen.

As discussed previously, we first attempted to control the FMC by using BASIC. This was in addition to programming the robot and develop-

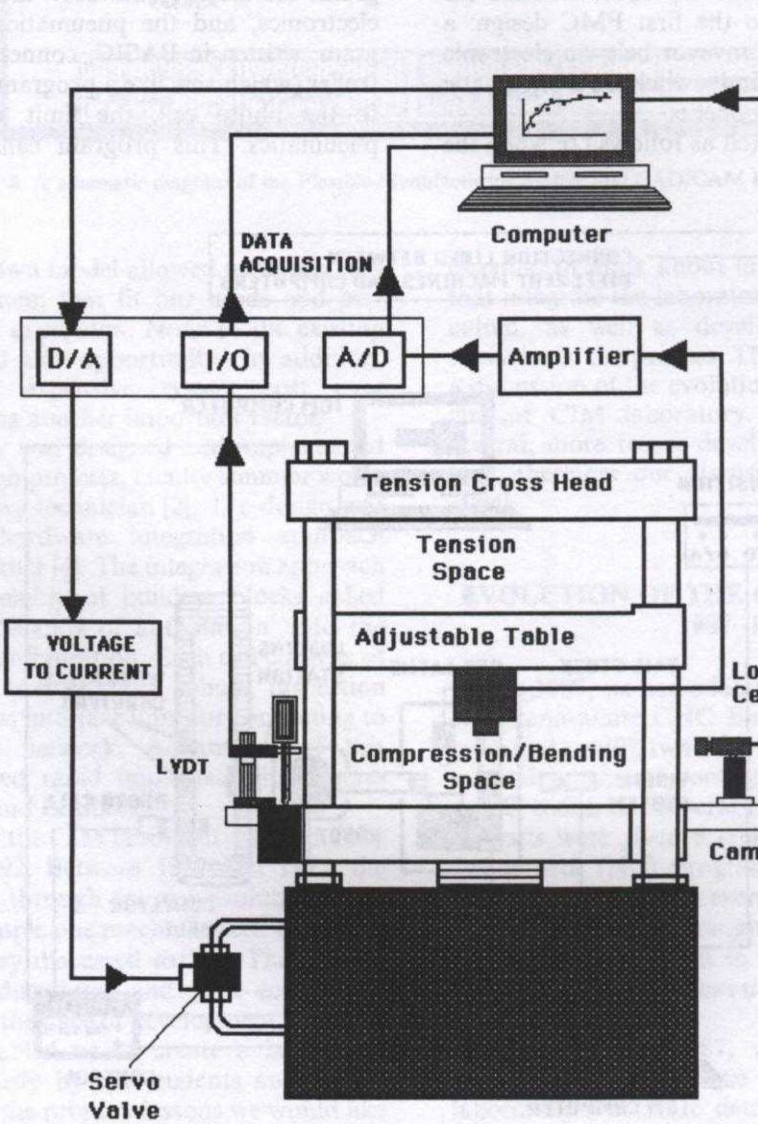

Fig. 6. A schematic diagram of the computer-controlled material testing machine.

ing the NC code for machining purposes. This attempt required many prerequisites from our engineering and other non-engineering students. For example, they were required to know the programming language, the host computer, and the communication protocol between the computer and the controlled cell (in this case it was the robot controller). To solve these problems, providing a higher level of communication in the FMC as well as allowing the students to spend more time on design instead of programming, we decided to introduce a new object-oriented programming language developed by two graduate students from the Systems Analysis Program.

The new language is called Cell-Programming Language (CPL). It allows the user to activate devices by using commands such as ON and OFF, as well as test the state of the devices. Also, a CPL program allows the user to send files of commands to programmable devices such as robots and CNC machines. Therefore, for our FMC we needed a CPL program in addition to several files of commands for the robot and the CNC machine [10, 11].

In 1992, we acquired an automatic storage and retrieval system made by Amatrol [3], and in 1993 a group of senior students integrated the system with the existing FMC (see Fig. 1). They developed a loading–unloading station (buffer) with another RM-501 robot at the end of the conveyor. They also developed a computer program (written in BASIC and down-loaded to the robot controller) that allowed the robot to pick up the finished machined part and place it on a special fixture to be picked up by the AS/RS robot. Another group developed a second program that allowed the user to place the fixture in any bay of the AS/RS and to program the AS/RS in advance with the required parts in specified bays. Later, the user can select any bay to store or retrieve the desired parts. It should be noted that part of this program utilized some of the existing software of the Amatrol AS/RS.

In 1993–1994, we added several computer simulation software packages to the laboratory, such as AT & T Witness [12] and ProModel [13]. These were utilized basically to allow the students to study and simulate several manufacturing processes with many machines and different parts, while encountering realistic constraints, such as cost. The software was introduced to the students during the laboratory period (more about this later), and they were required to complete exercises on the given problems as well as to solve specific homework problems. One group actually used the software to simulate a specific design for a real industrial situation—design of an automated system for Cymbals—as part of their senior design projects.

In the spring of 1994, we received a $100,000 grant from the FORD Company Education Foundation and an advanced controller from Cincinnati Milacron to continue improvement of the existing laboratory and to add more industrial equipment. Towards this goal, we are planning to expand the capabilities of the FMC cell by including a milling machine, a vibratory feeder and a vision system for quality-control purposes; to integrate the Milacron Controller with the existing equipment; and to broaden the type of exercises we offer to the students. Also, we are developing a new computer modular cell (see Fig. 4) that will allow the students to do more CAD/CAM and simulations.

INTEGRATING THE CIM LABORATORY INTO THE CURRICULUM

As we were developing the CIM laboratory, we were also engaged in restructuring our curriculum and deciding on new activities to incorporate the laboratory into the students learning experiences. We started by selecting three undergraduate courses to develop and utilize the laboratory. These courses are the sensor design projects, computer-integrated manufacturing systems (which was called computer-assisted manufacturing before 1992), and computer-aided experimentation (which, before 1992, used to be called instrumentation and measurements). A brief discussion of these courses is introduced below (for more details, see [2, 5–7]).

The first of the three undergraduate courses is the senior design project. This course of 4 credit hours (requires senior standing) is covered in two semesters, with 4 credit hours of design. The course is structured to resemble a modern workplace. The instructor acts as the team leader and the students are the employees. They report to the team leader and take responsibility for almost every detail in the project. There are no structured lectures as in other courses, but the class meets as individual groups at prearranged, specified times with the instructor. To select projects for the students, we normally contact local companies to see if they have specific problems that require research and development. For example, we offered the students projects from General Motors in Dayton, Ohio; the Ford Motor Company in Connersville, Indiana; and Wayne Industries, in Greenville, Ohio, which specializes in employing handicapped people for training and rehabilitation. We offer more projects than the given number of student groups in order to give students a chance to choose their projects.

The second course, Computer-Aided Experimentation, is a 4-credit, junior-level course with a 2-hour weekly laboratory and two credits of design. In this course, we consider design in the context of selecting and integrating instruments in automated-manufacturing systems (for more details, see [14]). The lecture covers the theory of instrumentation, measurements, and experimentation, while the laboratory is devoted to applications and open-ended design projects. The course is divided into three parts. During the first 5 weeks, the students are introduced to the design method as it pertains to the field of experimentation. In the second 4 weeks, the students are introduced to the data-acquisition system (DAS), and computer programs to interface instruments to the computer by using the DAS functions digital-to-analogue (D/A), analogue-to-digital (A/D), and digital-to-digital (I/O). The entire course culminates in the final 6 weeks as students complete open-ended design projects that capture the experience of the whole class. All projects utilize computers, DAS, and sensors to develop a working computer-aided experimentation system. Examples of previous projects include: a feedback-control system for a flexible-machining cell and a material-handling system; a vision-robot system for pattern recognition and material handling; an exercise machine for the elderly; and insect-mobile robots.

Computer-Integrated Manufacturing Systems, the third course, is a senior level course with 1 credit hour of design. In this course, the students actually work on problems related to the concept of CIM and attempt to integrate the different cells of the laboratory in their designs. The laboratory is divided into two parts. The first 6 weeks of semi-structured exercises allow them to rotate around four cells of the lab, which include a vision-robot based system, the FMC, and the AS/RS system. The second 4 weeks are spent on CAD/CAM designs and manufacturing of parts. In the final 5 weeks, students work on finishing their designs and products. For example, last year, the students were required to design and manufacture a scientific toy for local elementary students ages 7–12. At the end of the semester the students delivered their products to the students and their teachers.

In addition to these three courses, the laboratory is utilized in a few other courses throughout the manufacturing engineering curriculum. In the first semester of the freshman year, a 1 credit hour course entitled 'Introduction to Manufacturing Engineering' introduces the students to the laboratory through demonstrations of its different cells and links it to a general discussion about engineering, design, and modern technology. In another 3-credit-hour freshman general education course, 'Perspectives on Technology', (open to all non-major students) we introduce the students to the laboratory through several sessions that enable them to be acquainted with the technology in some depth. Other courses that utilize some elements of the laboratory are offered for students in the sophomore and junior years.

CONCLUDING REMARKS

In this paper we have explained the process that we used at the Manufacturing Engineering Department, Miami University, to develop and use a CIM lab. Rather than purchasing a turn-key commercial system, we chose an evolutionary process instead. In addition, the process involved interdisciplinary faculty members as well as undergraduate and graduate students from at least three departments: manufacturing engineering, systems analysis, and the ergonomic centre. Every year since 1987, we have added one small step to our existing laboratories to develop this new CIM environment. By 1992, we established a CIM laboratory that simulates a modern industrial environment and allows students to design and manufacture products. Also, the laboratory can be used for both undergraduate and graduate students' instruction and research.

Because we envision this CIM laboratory to continuously evolve and improve, we are planning the following future work: moving the laboratory to a production environment where students design and select materials, check inventory, plan production, and produce at least five or more different parts. At present, most of these activities are carried out, but not on a production and integration fashion that the CIM philosophy demands. We would like to introduce the business side to the laboratory by forming interdisciplinary projects that encompass business, engineering, and manufacturing thinking. In addition, we are interested in developing interdisciplinary activities for continuing education for industrial personnel, pre-college teachers, and students.

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Osama M. Ettouney is an associate professor and chair of the Manufacturing Engineering Department, Miami University. He earned his PhD degree in mechanical engineering from the University of Minnesota in 1987; his MS in mechanical engineering from MIT in 1981; and his BS in mechanical engineering from Cairo Institute of Technology, Egypt, in 1974. His teaching and research interests include: engineering design, computer-aided experimentation, and computer-integrated manufacturing systems. In addition, he has a special interest in pedagogy and computers application in the classroom.

Donald Byrkett is a professor and chair of the Systems Analysis Department, Miami University. He earned his PhD, MS, and BIE degrees in industrial engineering from the Ohio State University. He has consulting experience with General Electric Aircraft Company, Square-D Company, and Cincinnati Milacron. His teaching and research interests include: integrating computers and manufacturing systems, simulation of manufacturing systems, and computer applications in the classroom.