A comparative study on the manufacturing engineering education in Ontario universities.

Zhiqi. Zhong
University of Windsor

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A COMPARATIVE STUDY ON THE MANUFACTURING ENGINEERING EDUCATION IN ONTARIO UNIVERSITIES

by

Zhiqi Zhong

A Thesis
Submitted to the Faculty of Graduate Studies and Research through the Department of Industrial and Manufacturing Systems Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Applied Science at the University of Windsor

Windsor, Ontario Canada

2001

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Abstract

Manufacturing engineering plays an important role in the Canadian economy. However, progress made in improving the manufacturing engineering programs at the university level in Canada has fallen behind compared to what in other developed countries such as Germany, United States and Japan. In order to improve the competitiveness of the Canadian manufacturing industry, it is necessary to reinforce the manufacturing engineering education programs, especially the undergraduate programs.

The objectives of this thesis are to find the limitations of the Canadian manufacturing engineering education programs and accordingly, to propose improvement. The thesis begins with a general review of some manufacturing engineering programs in other countries around the world. Then a study of the current status of manufacturing engineering education in Canada, with a focus on the undergraduate manufacturing engineering education in Ontario, is reported. The needs of current and future Canadian manufacturing industry and the functions of manufacturing engineers in the future are discussed. Finally, in order to solve the problem of the lack of hands-on experience in the existing programs, a proposal of a Manufacturing Engineering program with a Computer Integrated Manufacturing (CIM) Laboratory is presented.
Acknowledgements

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CHAPTER 1 – INTRODUCTION

Manufacturing is a key element to the success of many nations including the United States, Japan and Germany (Zemmerman, 1996). Today, most countries recognize the importance of manufacturing and manufacturing engineering education.

Engineering Education in Canada began in the late 19th century (Dwyer 1997). Formal courses in engineering followed the establishment of schools and colleges of engineering and science in eastern Canada. Since then, general engineering has been expanded and divided into a wide variety of fields, such as Mechanical Engineering, Industrial Engineering, Civil Engineering, Chemical Engineering and Electrical Engineering. Today, more than 80 percent of Canadian universities are offering accredited (by Canadian Engineering Accreditation Board (or CEAB)) 4-year degree programs leading to the B. Sc. (Bachelor of Science), B. A. Sc. (Bachelor of Applied Science) or B. Eng. (Bachelor of Engineering) in different engineering fields. Many of them also offer postgraduate programs leading to Master’s (M. Sc., M. A. Sc. or M. Eng.) and Ph.D. degrees.

Technological advances will continue to progress over the next several decades. In manufacturing engineering, these advancements will include new manufacturing processes, computer control, wireless communication and information systems, etc. Among them, Computer-Aided Design (CAD) and Computer-Aided Manufacturing
(CAM) have brought about dramatic improvements in production quality, manufacturing productivity and product diversity (Fletcher, 1997).

Dynamic changes in industry require engineering educators to re-structure their curriculum to embody these new technologies within the course content. Therefore, engineering programs must constantly evolve to accommodate technological advances and at the same time maintain a focus on the fundamentals that serve as the engineering foundation of the industry.

Since the late 1960's, the call for Manufacturing Engineering as an independent discipline became stronger in North America. In Canada, the first accredited Manufacturing Engineering program emerged at McMaster University in 1982 (CEAB Annual Report, 1998). Although there are not independent Manufacturing Engineering departments in Canadian universities, manufacturing engineering has always been an important part in Canadian engineering education. In Ontario, there are 11 universities which provide manufacturing courses from traditional Manufacturing Technology to modern Computer Aided Design/Computer Aided Manufacturing (CAD/CAM).

With the rapid advance of computer technology, the use of computers in manufacturing has grown steadily. Computer Integrated Manufacturing (CIM) has become a very important way to improve an enterprise's competitiveness in the global market (Shrensker, 1990). Although the benefits of CIM are apparent to the enterprises, the implementation of CIM has not been very widespread. Obstacles to CIM
implementation include philosophical, managerial, financial, and technological factors. A closer look at these obstacles reveals that many of them are attributed to inadequate and ineffective education. Skilled personnel who can work within such an environment have been in severe shortage (Edan and Livshitz, 1997). Under this circumstance, both academia and industry have to recognize and advocate the need for effective education and training in order to equip students to fit into a modern manufacturing environment - for present needs as well as for the future.

The importance of using laboratories in manufacturing engineering education is an issue that has been discussed extensively (White, 1993). A laboratory provides not only invaluable support for the students in understanding the basic principles, but also the much needed hands-on experience for the students to become practiced engineers. Unfortunately, laboratories in Canadian universities are poorly supported in both capital equipment and manpower management funding. Nevertheless, although many problems can not be solved without strong support from the government and the industry, much improvement can be made with a creative mind and limited investment. The objective of this study is to investigate the existing problems in Canadian manufacturing education and accordingly, to propose a cost-effective way to improve the manufacturing engineering education through the CIM laboratory.
CHAPTER 2 - LITERATURE REVIEW

The thesis begins by defining the terms of Manufacturing Engineering and Manufacturing Engineer. A clear understanding of these definitions will help educators to make improved decisions regarding course/program content. There follows review of the relevant literature concerning engineering programs and manufacturing education, with a particular focus on the undergraduate programs in manufacturing engineering.

2.1 Definition of Manufacturing Engineering

The Society of Manufacturing Engineers (SME) has defined Manufacturing Engineering as (Riley, 1992):

that specialty of professional engineering which requires such education and experience as is necessary to understand, apply and control engineering procedures in manufacturing processes and methods of production of industrial commodities and products, and requires the ability to plan the practices of manufacturing, to research and develop the tools, processes, machines and equipment, and to integrate the facilities and systems for producing quality products with optimal expenditures.

SME has also stated that:
Engineering involves a high degree of creative activity in the identification of theories and their development into practical applications. It is at this level that concepts are formulated and ideas are transformed into design and product engineering activities. The manufacturing process begins with the engineered product and ends with the final operation on the production line; in between product engineering and distribution lies the industrial function called manufacturing engineering.

In practice, the manufacturing engineer performs many tasks in a wide range of industries. An encompassing definition, if necessary, must be very general. A definition supplied by the U.S. Department of Labour defines a manufacturing engineer as one who (Riley, 1992):

directs and coordinates manufacturing processes in industrial plants; determines space requirements for various functions, and plans or improves production methods including layout, production flow, tooling and production equipment, material fabrication, assembly methods and manpower requirements; communicates with planning and design staffs concerning product design and tooling to assure efficient production methods; estimates production times and determines optimum staffing for production schedules; applies statistical methods to estimate future manufacturing requirements and potential; approves or arranges approval for expenditures; and reports to management on manufacturing capacities, production schedules and problems to facilitate decision making.
These definitions are widely accepted by industrial and mechanical engineers since they are quoted in the Maynard's Industrial Engineering Handbook (Fourth Edition, 1992) and ASME (American Society of Mechanical Engineers) Handbook (Third Edition, 1995). The definitions indicate that manufacturing engineering is a comprehensive industrial activity. It links engineering design and production. A qualified manufacturing engineer requires engineering knowledge as well as practical production experience. With the widespread application of computers in manufacturing engineering, the old view of manufacturing as a shop-floor activity is fast disappearing. Manufacturing engineers should be not only technical specialists, but also operations integrators in the enterprises.

2.2 A review of manufacturing education in some countries

In 1994, SME conducted a large project called “Compendium of International Models for Manufacturing Education” to study manufacturing education programs in major countries around the world (SME Proceedings on Manufacturing Education for the 21st century, Volume II, 1995). The aim of the project was to create international models for manufacturing education. The project was done through the assembly of individually-prepared plans which described and discussed university-level manufacturing engineering education in major industrial nations and regions of the world. In the SME report, a total of twenty-seven countries were identified as representing the industrialized nations with major international manufacturing stature. According to the report countries such as the
United States, Japan, Germany, China, India, Singapore, Sweden and Spain either made significant contribution to their GDP (Gross Domestic Product) or achieved significant growth in the contribution of manufacturing to their GDP. Table 2.1 (World Statistics Pocketbook, 1999) shows the contribution of manufacturing sector to the GDP of these countries.

### Table 2.1 Relative contribution of manufacturing to GDP of some industrial countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Real 1997 GDP (Billions of U.S. $)</th>
<th>Manufacturing Contribution to GDP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>$7,815.77</td>
<td>31.3</td>
</tr>
<tr>
<td>Japan</td>
<td>$5,390.59</td>
<td>47.1</td>
</tr>
<tr>
<td>Germany</td>
<td>$2,502.85</td>
<td>46.3</td>
</tr>
<tr>
<td>China</td>
<td>$828.02</td>
<td>26.4</td>
</tr>
<tr>
<td>Spain</td>
<td>$591.65</td>
<td>38.6</td>
</tr>
<tr>
<td>India</td>
<td>$364.45</td>
<td>23.1</td>
</tr>
<tr>
<td>Sweden</td>
<td>$251.75</td>
<td>33.5</td>
</tr>
<tr>
<td>Singapore</td>
<td>$93.71</td>
<td>40.5</td>
</tr>
</tbody>
</table>

The United States of America, Japan and Germany are the economic powerhouses amongst the seven most advanced industrial countries. Studies and research reveal that their successes are related to the role of manufacturing education in their national infrastructures. Countries in Europe and Asia are in the same situation.
Most of the countries have distinct/separate manufacturing programs, including the following courses:

1. Design for production, CAD/CAM
2. Materials;
3. Manufacturing processes;
4. Manufacturing systems and automation;
5. Controls;
6. Manufacturing management.

These courses can be classified into three categories (Kosmol, 1996; Lippold 1996; Ponsen and Kals, 1996). The first category focuses on manufacturing processes. They cover both classical processes such as metal cutting and modern processes such as injection molding. The second one focuses on engineering materials. These courses have been in existence in engineering education for a long time. They are often used in manufacturing programs in their original format or in programs which have been slightly modified. Courses in the third category focus on individual topics in contemporary manufacturing such as DFA (Design for Assembly), DFM (Design for Manufacturing), concurrent engineering, green technology, etc. (Radcliffe, 1996; Weill and Weiss, 1996).

In the United States, manufacturing education at the university level has two parallel paths: Manufacturing Engineering Technology (MfgET) and Manufacturing Engineering (MfgE). The former is generally designed to concentrate on applications of
technology and to solve production problems. It emphasizes laboratory studies, stresses the use of practical data and places less emphasis on theoretical foundations and mathematical modeling. The latter program is more conceptual and analytical containing a stronger mathematical and science foundation.

In the 1970s, there was a rapid growth of academic programs in MfgET. Currently three degree levels are available: the Associate (first-degree level), Baccalaureate and Masters. The most common degree programs are at the bachelor level. According to statistics (Wells, 1994) there was a total of 759 technology programs accredited by the Accreditation Board for Engineering and Technology (ABET). Among them, 45 were identified as manufacturing engineering programs, including 15 associate degree and 30 baccalaureate degree programs. (Wells, 1994)

As for MfgE programs, three degree levels are available: Baccalaureate, Masters and Doctorate. Until 1994, there were 86 universities offering programs or options in MfgE Baccalaureate degree, 83 universities with Masters programs and 26 with Doctorate programs in manufacturing engineering. Many of the post-graduate programs were initiated in the 1980's. (Wells, 1994)

Manufacturing engineering programs are not as popular in the US as they are in Germany and Japan for various reasons such as job perspective, national policies and competition from the imported labour force.
Japan’s success in manufacturing is well known to the world. Ranking by total revenue, 10 out of the 30 largest electronic companies in the world are Japanese (Ernst, 1996). Another notable observation is that nearly fifty percent of Japan’s revenue is derived from exports. The same accomplishment is achieved in other manufacturing sectors in Japan including automobiles, household goods, etc. Such a high level of development is caused by many factors, but one of the most important is education (Iwata and Onosata, 1995).

There are 36 public and 357 private four-year universities and 44 national, 54 public and 477 private 2-year colleges in Japan. Eighty-two percent of the universities and colleges have undergraduate and postgraduate manufacturing engineering programs (Japanese colleges and universities, 1995). A report presented by Dr. Iwata and Dr. Onosata in 1995 pointed out that manufacturing engineering courses in Japanese universities can be categorized into five groups:

- Design for Manufacturability
- Materials in Manufacturing
- Manufacturing Processes
- Manufacturing Systems and Automation
- Manufacturing Management

Germany’s manufacturing education system has been well developed since the 1970’s. The education of manufacturing engineers in the universities is usually assigned
to the special field of mechanical engineering. 18 of its total 29 engineering universities offer a specialist curriculum in manufacturing engineering (Eversheim, 1995).

The general perception among educators in the engineering field is that while the North American engineering schools are more science and computer oriented, the German universities emphasize practical skills. All German engineering students must go through Praktikum while in the North American program, only a certain portion of the engineering students go through a comparable co-op program (Taylan, 1996).

In Germany, the course time officially required to complete a Bachelor degree is 8 to 9 semesters. The actual length for completing the program takes between 12 and 14 semesters. This includes the time for general practice and thesis. In brief, the structure of the curriculum in the main program of manufacturing engineering in Germany is subdivided into:

- General Subjects (4 semesters)
- Specific Subjects (4 semesters)
- General Practice (3-5 semesters)
- Thesis (1 semester)

The above curriculum structure reflects the perception that the German universities emphasize practical skills in design and manufacturing. The 3-5 semesters general practice period is from 1 to 3 semesters longer than that in other countries.
In Sweden, a manufacturing model has been developed to co-ordinate education, research and co-operation between universities and industry (Novak, 1996). It was pointed out that the development of manufacturing technology, the variety of new demands and the emphasized usage of computers together shape manufacturing education in Sweden (Novak, 1996). The proposed model reflects this thought. The basic manufacturing courses in the model are CAD/CAM, FMS, Robotics, machine tools, Group Technology and manufacturing management. In these courses, the computer technology is used to teach the capabilities of a computer as an element of a manufacturing sub-system (a machine tool or an industrial robot for example), the types of problems to be solved, and the kinds of information needed to solve the problems. The Swedish government provides strong financial support to the universities in order to maintain advanced manufacturing and computer equipment in Swedish universities. Thus, the manufacturing engineering programs in Sweden have strong competitiveness compared with those in other countries and attract many students.

Spain began to become involved in Advanced Manufacturing Technologies (CAD, CAM, FMS, Robotics, etc.) in the early 80's and soon people found that the major problem to overcome was the education and training of people involved in the manufacturing industry. Realizing the problem, research and education in this domain were introduced at the university level in the late 80's. For example, a compulsory CAD/CAM/CAE project course was successfully introduced into the final year of the mechanical major in the University of the Basque County and it has been running since
1986 (Fernandez, 1996). The purpose of the course is twofold: the first is to help the students to become familiarized with a CAD/CAM/CAE commercial package, and the second is to design and manufacture a prototype. Other basic topics in Spanish Manufacturing programs include CAD/CAM/CAPP (Computer Aided Process Planning), Manufacturing Processes, NC (Numerical Control) and Flexible Manufacturing, and Production Management, etc. (Fernandez, 1996).

Asian economic growth has achieved remarkable levels of success over the last two decades. This is the result of the effort put into the education and training of human resources in relation to the manufacturing industry domain. Through reviewing the higher education in China, India and Singapore, it is noticeable that some Asian countries have put increasing effort into integrating the advanced manufacturing technologies into their engineering education programs (Soesilo et al., 1996).

China’s manufacturing engineering education emphasizes combining theory and practice. From absorbing the advanced education experience of other countries, Chinese universities started to incorporate the new manufacturing technologies into the traditional programs (Chen, 1995). Courses in undergraduate programs include: Technology of modern manufacturing; Numerical control of machine tools; Intelligent control of machines; and Manufacturing automation (CAM, CAPP, and CIMS) etc.

India has recognized technology education as one of the most crucial components of human resources development with great potential for contributing to the national
economy. Manufacturing engineering, as in many other countries, is relatively new as a separate academic discipline in India (Raju, 1995). In recent years, an increasing number of engineering institutions have started manufacturing related programs under the name of Production Engineering. The common manufacturing engineering program is eight semester long for undergraduate students. Advanced manufacturing related courses include: Computer Programming, Numerical Methods, Modern Machining Processes, Computer Graphics and Design and CAD/CAM Lab.

Singapore has experienced a dramatic economic transformation since the early 1960s. It's economic development strategy places strong emphasis on both manufacturing and services as the twin engines of growth (Nee, 1995). Sufficient numbers of trained engineers and technicians are crucial to sustain the growth of the manufacturing sector. Education and training are mainly provided by the Departments of Mechanical & Production Engineering or Manufacturing Engineering in universities and polytechnics in Singapore. The subjects taught at both the university level and within polytechnics are well supplemented with laboratory and tutorial classes to support the lectures. All the tertiary institutions in Singapore have very well equipped CAM/CAD centers with large numbers of the latest workstations and software packages. This puts manufacturing engineering education in Singapore in a relatively leading position in the world.

In conclusion, the root of success of these countries is related to manufacturing education. Historically, traditional manufacturing courses have been an integral part of mechanical engineering programs (Dwyer, 1997). Manufacturing engineering is
nowadays perceived as a respectable intricate discipline, as are other engineering disciplines. Of the countries being reviewed, notable trends in the teaching of manufacturing courses can be found in the increasing use of computers, especially with CAD/CAM technologies and computer simulation techniques.

2.3 Perspectives on CAD, CAM, CAE and CIM (C4)

CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAE (Computer Aided Engineering), and CIM (Computer Integrated Manufacturing) describe four separate but closely related disciplines in computer applications: computer-aided design/drafting, computer-aided manufacturing, computer-aided engineering, and computer-integrated manufacturing. The common goal of all these areas is to use the computer’s huge memory capacity, fast processing speed, and user-friendly interactive graphics capabilities to automate and tie together otherwise cumbersome and separate engineering or production tasks, thus reducing the time and cost of product development (CAD/CAM Handbook, 1996).

CAD is used to define some types of geometry for a mechanical part, architectural structure, electronic circuit, building layout, or other items. This information is stored in a computer database from which it is the basis for further work and to produce engineering drawings. The term CAD is often used to refer to 3D (3 Dimensional) work in computer-aided design and 2D (2 Dimensional) computer-aided drafting. Some people refer to the entire spectrum of this technology as computer-aided design and drafting, or CADD (CAD/CAM Handbook, 1996).
CAM systems provide the data and instructions to automated machines for making parts, assemblies, and circuits, often using the geometric data of a part or product from CAD as a starting point.

CAE is used to analyze CAD geometry, allowing the operator to simulate and study how the product will behave so that the design can be refined and optimized.

CIM is concerned with using computer databases as a way to more efficiently run an entire manufacturing system, affecting areas such as design and production, accounting, factory management, scheduling, and shipping (Rembold et al., 1993). The integration feature makes CIM different from CAD/CAM/CAE, which are concerned with engineering design and production functions. CIM is often said to be more of a business philosophy and a management strategy rather than a computer system. Figure 2.1 gives a clear picture of the relations between CAD, CAM, CAE and CIM (Chasen, 1995).

Practically, there is no rigid order in which CAD, CAM, CAE, and CIM functions are performed. In many cases, CAD is used first to create an initial design, which is then analyzed with CAE and cycled back through CAD until it is sufficiently optimized. CAM is then used to produce the product. In other cases, however, CAE is used to analyze products that are already manufactured, but experiencing problems. In some of the most recent implementations of CAE, analysis is being done in the initial conceptual stage of product development to refine ideas before CAD is even started. Also, some systems
incorporate design and analysis so closely that CAD and CAE functions are performed almost simultaneously by one operator on the same system. From Figure 2.1 on the next page, we can see clearly that it is CIM which ties each of these functions to each other and the entire enterprise.

The idea of using computers in analysis, design and manufacturing is not new, but its implementation in a Computer Integrated Manufacturing environment in which the computer achieves its maximum potential remains a challenge for industry and educators alike. Because of the fact that CIM should be taught as a strategy (Aletan, 1991), its education must involve all levels of management and engineering. The students should be exposed to a variety of fields, such as automated production, CAD, computer control, robotics, artificial intelligence, and machine vision. This can be achieved by developing a CIM laboratory for the engineering program. Students can gain practical experience through manufacturing simple products using advanced automation techniques and equipment. CAD/CAM, as the Engineering function of CIM, should be integrated into the curriculum through the CIM laboratory.
Figure 2.1 Relations of CAD, CAM, CAE, and CIM
2.4 Manufacturing Engineering in the future

According to a study conducted by the American Society of Mechanical Engineers (ASME) in 1995, the following subjects are identified as important foundations for manufacturing education:

(1) Computer Integrated Manufacturing (CIM),
(2) Design for Manufacturing,
(3) Manufacturing Processes,
(4) Manufacturing Floor/Workcell Layout,
(5) Robotics and Automated Assembly,
(6) Materials Planning-Inventory,
(7) Electro-mechanical Packaging, and
(8) Total Quality Management.

Profile 21 (Arthur, 1990)- a study conducted by the Society of Manufacturing Engineers (SME) has sought to alert people with involvement in manufacturing to the accelerated and on-going changes in markets, products, and technologies. Some of their findings about the future are summarized below:

(1) **Environmental changes**

Manufacturing engineering faces increased product sophistication and variation, global manufacturing competition, and a multitude of social and economic changes.

(2) **Changing roles of manufacturing professionals**

The manufacturing engineer will be a technical specialist, operations integrator, and enterprise strategist. (Figure 2.2)
(3) **New and advanced tools/technologies**

This includes the increased use of computers and software, the use of expert systems, neural networks and AI applications, and sophisticated communication systems.

(4) **Changing emphasis in the workplace**

This includes more of a team focus and increased importance for human relations.

![Diagram](image)

**Fig. 2.2 Illustration of the role of manufacturing engineer**

For the manufacturing engineer, each of these roles requires the balance of depth and breadth of skills. The depth of skills includes the traditional technical engineering disciplines. The breadth of skills includes non-technical capabilities such as effective communications, foreign language fluency, teamwork, and the ability to deal with broader business issues (Peklenik, 1996).
The manufacturing engineers of the future will have to play a greater role as system integrators and enterprise strategists than ever before. These changing roles will require engineers to acquire and assimilate a broad-based knowledge in order to handle the challenges from business to engineering, and from strategic planning to operational issues. Paradoxically their abilities to master these challenges will determine to a significant extent the level of success for their organizations.

In 1993, the Society of Manufacturing Engineers (SME) started a study to determine what the manufacturing engineer's job description would look like by the year 2000, and to ascertain what additional steps, if any, ought to be set in order to prepare new engineers for the profound changes that were anticipated. The study was finished in 1996 and the results are shown in Table 2.2.

The forecast shows that manufacturing engineers will increasingly be involved in a variety of tasks and activities inside and outside an enterprise. From the above table, we can also observe that manufacturing systems will tend to be more automated in the future because of the application of computer technology. Expert systems and artificial intelligence techniques will be widely used in the 21st century. Although the increased percentage of CIM systems and CAD/CAM, CAPP and CAE are only 30 percent and 13 percent, it should be noted that they are already used broadly in companies as shown by 27 percent and 56 percent in current usage.
Table 2.2: Forecast of technologies used in manufacturing (Shea et al., 1996)

<table>
<thead>
<tr>
<th>Technology contents</th>
<th>Current usage (%)</th>
<th>Required usage in 2000 (%)</th>
<th>Increase (%)</th>
<th>Growth multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert systems, artificial intelligence</td>
<td>11%</td>
<td>47%</td>
<td>36%</td>
<td>4.3</td>
</tr>
<tr>
<td>Automated material handling</td>
<td>23%</td>
<td>58%</td>
<td>35%</td>
<td>2.5</td>
</tr>
<tr>
<td>Sensors and control</td>
<td>16%</td>
<td>51%</td>
<td>35%</td>
<td>3.2</td>
</tr>
<tr>
<td>Laser applications, including welding, heat treating and inspection</td>
<td>17%</td>
<td>51%</td>
<td>34%</td>
<td>3.0</td>
</tr>
<tr>
<td>CIM systems</td>
<td>27%</td>
<td>57%</td>
<td>30%</td>
<td>2.1</td>
</tr>
<tr>
<td>Advanced inspection technologies, including on-machine inspection and clean room technology</td>
<td>32%</td>
<td>57%</td>
<td>24%</td>
<td>1.8</td>
</tr>
<tr>
<td>Flexible manufacturing systems</td>
<td>32%</td>
<td>56%</td>
<td>24%</td>
<td>1.8</td>
</tr>
<tr>
<td>Simulation</td>
<td>17%</td>
<td>40%</td>
<td>23%</td>
<td>2.4</td>
</tr>
<tr>
<td>Composite materials</td>
<td>16%</td>
<td>36%</td>
<td>20%</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>CAD, CAM, CAPP and CAE</strong></td>
<td><strong>56%</strong></td>
<td><strong>69%</strong></td>
<td><strong>13%</strong></td>
<td><strong>1.2</strong></td>
</tr>
</tbody>
</table>

Since their inception, high-speed digital computers have been used extensively in all engineering work, including engineering design. Not only the large companies but
more and more medium size and small size firms are now using this powerful tool with the result that the number of CAD/CAM installations has been increasing by more than 30 percent a year since the mid 80's (Machover, 1995).

With the rapid development of hardware and software used in CAD/CAM, undergraduate engineering education must change markedly in order to prepare graduates adequately for current and future state-of-the-art engineering activities. Therefore, CAD/CAM is considered as the manufacturing core course by many universities in their Mechanical Engineering or Industrial Engineering programs.

In the following chapters, the author will propose an approach to integrate CAD/CAM technology into the undergraduate engineering program for students in Ontario universities through the development of a CIM laboratory in IE or ME departments. The aim is to try to prepare the students to fulfill the future requirements of a manufacturing engineer.
CHAPTER 3 – CURRENT MANUFACTURING EDUCATION IN ONTARIO

This chapter gives a review of the present status of manufacturing education in Ontario.

3.1 The Manufacturing Industry in Canada and Ontario

Manufacturing in Canada had its beginnings early in the 18th century, but it was not until the late 19th century, with the availability of electricity and the development of a national political objective, that it achieved significant growth. Throughout the 20th century, manufacturing has contributed significantly to the economic well-being and prosperity of Canadians.

Based on the information from the Canada Yearbook 1997, manufacturing contributed to 18 percent of Canada’s Gross Domestic Product (GDP) and employed about 15 percent of the national workforce (roughly 1.9 million people) in 1995. In 1997, the manufacturing sector exported 182 billion Canadian dollars worth of products. Manufacturing and its “value-added output” (a financial measurement of what manufacturers actually produce minus the materials and energy consumption) rose since the 1980s. The manufacturing sector of Canada is part of a complex logistics network which is related to a much wider economy. For every 3 new jobs created in
manufacturing, about 3 related jobs are created, i.e., one each in the service sector, the resource sector and in a related manufacturing industry (Bothwell and Hillmen, 1998).

Ontario is the leading manufacturing province in Canada (Bothwell and Hillmen, 1998). Its proximity to the American automotive industry encouraged the location of manufacturing plants in Ontario. The establishment of Ford, General Motors and Chrysler in Ontario in turn spun off vast groups of related industries dotted all across southern Ontario. In recent years, Japanese automotive companies such as Honda and Toyota have also invested heavily in plant and machinery in this province. Transportation equipment of all kinds, including aircraft and railcars, accounts for $1 out of every $5 of value-added production in industrial Ontario. In 1995, there were 1,400 transportation equipment plants in Canada. Half of them were in Ontario and employed three-quarters of all industry employees (Canada Year Book, 1998).

With over 12,000 manufacturing establishments in Ontario in 1996 providing employment for 850,000 people, Ontario produces over half the gross domestic product of all manufacturing industries in Canada (Bothwell and Hillmer, 1998). Nevertheless, these figures are down significantly from only 5 years before, when there were 15,500 establishments providing 945,000 jobs. Metropolitan Toronto has half of all provincial manufacturing establishments, followed by Hamilton, Windsor, St Catharines-Niagara and London. During the late 1970s, Ottawa, frequently seen as a staid national capital completely dependent on the largesse of the federal government, confounded its critics by emerging as Canada's equivalent of California's Silicon Valley, a centre for high technology industries, producing computers, communications technology and software.
Ontario accounts for almost 60% of Canada's high-tech output, but remains (like the rest of Canada) a net importer of technology (Dwyer, 1997).

In the 1990s, as trade barriers have lifted around the world, the marketplace has become increasingly global in scope. This has created greater foreign competition for Canadian manufacturers, but also has led to new markets abroad. To compete, manufacturers have continued to invest in new technologies, and to seek more highly trained workers. With the increasing demand for higher educated and well-trained employees by the enterprises, there has been less need for unskilled labor. The growing connection between education and job prospects is reflected by the following figures provided by Statistics Canada in 1998. Over the past decade, 17% of jobs that required high schools skills or less have disappeared; at the same time, the number of jobs for people with post-secondary education and training or better has grown by nearly 30%.

The above phenomenon provides a strong incentive for the Canadian academic community to prepare skilled employees for industry. The important role of manufacturing engineering in the Canadian economy, especially in Ontario, makes it necessary for engineering educators to equip students with advanced manufacturing knowledge such as CAD, CAM and CIM.
3.2 The Current Manufacturing Education Programs in Ontario

In Canada, there exist two main types of schools providing post-secondary manufacturing engineering education: the university and the college. The former is aimed at producing engineers while the latter is designed for engineering technologists, technicians and technical specialists; these are primarily offered through manufacturing technology departments and programs within the Canadian community college system.

There are a large number of colleges in Canada, offering certificates and diploma studies for technicians or technologists. Few offer a bachelor's degree. Colleges are not accredited by CEAB (Canadian Engineering Accreditation Board), and graduates do not generally qualify for registration in the Province Professional Engineering Associations, such as PEO, the Professional Engineers of Ontario. Instead, students who graduate from colleges are encouraged to seek professional standing through Associations such as OACETT (Ontario Association of Certified Engineering Technicians and Technologists).

Most colleges offer diploma courses in many areas relating to Technology, Manufacturing and Business. A typical college "Manufacturing Engineering Technology" program is a three-year diploma co-operative education program. Many colleges also provide different programs with a strong manufacturing bias, e.g., Mechanical Engineering Technician and Technician/drafting programs, and the Mechanical Engineering Technology and Technology Design Drafting programs. Currently, for Ontario, the College's provincial share of enrolment for machine shop technicians is 77
percent, and for mechanical engineering technologists is 32 percent (St. Clair College of Applied Arts and Technology, 1998). The colleges also have responded to students who may wish to pursue university studies through programs leading to a "seamless transition" or a "bridge" to a university degree.

Many of the leading Ontario colleges have a Program Advisory Committee (PAC) consisting of people from business and industry. The PAC is responsible for ensuring that programs are up to date and relevant. With the expansion and importance of the usage of computers in manufacturing in the last few years, Computer-Aided Design and Computer-Aided Manufacturing are included in more and more manufacturing engineering technology subjects. Most program courses offer hands-on laboratory assignments for traditional machine shop practice as well as for flexible manufacturing systems and computer integrated manufacturing (CIM). In Seneca College in Toronto, there are two 2-year programs, Manufacturing and Machining techniques and Mechanical Engineering Technician, which offer Computer Numerical Control, Computer Assisted Machining, CAD/CAM and Automation and Controls courses. Laboratory components are included for these advanced manufacturing technology courses.

Ontario colleges generally have excellent manufacturing laboratories. In order for other educational organizations and industries to participate in sharing laboratory facilities and human resources, collaborative arrangements between universities, colleges, and industries have been formalized. The emerging model is driven by a desire to fulfil the expectations of students, employers and the university administration in providing
excellent and relevant education by adopting innovative techniques and ensuring high efficiency. For example, the Manufacturing Resource Institute (MRI) is such a collaboration between the University of Windsor, St. Clair College, business, industry, and other organisations. Objectives include: applied research, streamlining and co-ordinating curricula in engineering and business programs, and sharing resources. (St. Clair College of Applied Arts and Technology, 1998)

Canadian universities produce graduates in various engineering disciplines with B.Sc., B.A.Sc. or B.Eng. degrees. Most universities offer several courses related to manufacturing engineering in the department of Mechanical/Industrial Engineering. A final (4th) year design project is a compulsory course in Canadian universities. Some offer co-operative or professional industrial internship training, which is intended to provide opportunities for students to practice textbook knowledge through real manufacturing job assignments.

Among the sixty-two Canadian universities, there are thirty-three universities offering engineering and engineering related programs such as Mechanical Engineering, Civil Engineering, Electrical Engineering and Industrial Engineering (Statistics Canada, 1997). McMaster University (since 1982) and the University of Calgary (since 1997) are the only two that offer CEAB (Canadian Engineering Accreditation Board) accredited manufacturing engineering programs for their undergraduates (CEAB Annual Report, 1997). Some universities provide a Manufacturing Engineering option for the undergraduate students, e.g. the Manufacturing Engineering option in Mechanical
Engineering department in the University of Western Ontario. The most common manufacturing related courses are Manufacturing Processes, CAD/CAM, Robotics and CIM. These courses are usually provided in the third or fourth year of the undergraduate program. Some of the courses are offered as electives.

Ontario has the largest and most extensive university system in Canada. There are nineteen universities in Ontario, and of these, thirteen universities offer engineering programs. These universities are:

(1) Carleton University,
(2) University of Guelph,
(3) Lakehead University,
(4) Laurentian University,
(5) McMaster University,
(6) University of Ottawa,
(7) Queen’s University,
(8) Ryerson Polytechnic University,
(9) Royal Military College
(10) University of Toronto,
(11) University of Waterloo,
(12) University of Western Ontario,
(13) University of Windsor.
The Canadian Engineering Accreditation Board (CEAB), a standing committee of the Canadian Council of Professional Engineers (CCPE), monitors the quality of the engineering academic programs.

Most universities that offer engineering programs have a common first year curriculum, which usually consists of courses in basic sciences (chemistry, mathematics, physics) and technical communication (e.g. English writing) (CEAB Annual Report, 1998). However, the courses offered in years two to four are different from university to university. Of the thirteen universities indicated earlier, eleven of them offer manufacturing related courses, as summarized below. Those courses which are required for a manufacturing engineering option are indicated by "*"; others are technical elective courses. The time unit for each course is given as hours per week. For example, lecture: 3 means 3 lecture hours per week.

(1) Carleton University.

In the Department of Mechanical Engineering in Carleton University, a special concentration in Computer-Integrated Manufacturing (CIM) is available for students with an interest in this area. The concentration is designed to provide an understanding of the issues, concepts and techniques of applying computer technology to design and manufacturing.

The concentration consists of the following courses:
Principles of Manufacturing Engineering (lecture: 3, laboratory: 1) *

An Introduction to Robotics (lecture: 3)

Finite Element Methods (lecture: 3)

CAD/CAM (lecture: 3) *

(2) Lakehead University.

The Department of Mechanical Engineering at Lakehead University offers:

Finite Element Methods (lecture: 3, laboratory: 1.5)

Introduction to Robotics (lecture: 3, laboratory: 1.5)

Manufacturing Processes and Production Systems (lecture: 3, laboratory: 1.5) *

(3) McMaster University.

McMaster University is the only school in Ontario that has a Manufacturing Engineering program accredited by CEAB. The Department of Mechanical Engineering offers the following courses:

Manufacturing Engineering (lecture: 3, laboratory: 2) *

Project in the area of manufacturing engineering (laboratory: 6) *

Manufacturing Processes (Metal Removal) (lecture: 3, laboratory: 1) *

Finite Element Applications (lecture: 3)

Computer Aided Manufacturing (lecture: 2, laboratory: 3) *
Computer Aided Design (lecture: 2, laboratory: 1)

Introduction to Robotic Mechanics (lecture: 3)

(4) University of Ottawa.

The Department of Mechanical Engineering offers:

Computer-Aided Design and Manufacturing (lecture: 2, laboratory: 6) *

Manufacturing Engineering (lecture: 3, laboratory: 2) *

Finite Element Analysis (lecture: 3)

Quality Control in Equipment Design and Manufacturing (lecture: 3)

Advanced Production Planning & Control (lecture: 3) *

(5) Queen’s University.

The Mechanical Engineering curriculum in Queen's University provides courses unique to the discipline of machine design and manufacturing methods. The manufacturing related courses include:

Manufacturing Methods (lecture: 3, laboratory: 2)

Manufacturing Engineering (lecture: 2, laboratory: 1, tutorial: 1)

Computer-Aided Design (lecture: 3, laboratory: 1)
(6) **Royal Military College at Kingston**

The Department of Mechanical Engineering offers:

Computer-Aided Design and Manufacturing (lecture: 3, laboratory: 1)

(7) **Ryerson Polytechnic University**.

The Department of Mechanical Engineering offers:

Automated & Manual Manufacturing (lecture: 4)

Manufacturing Fundamentals (lecture: 4, laboratory: 1) *

Computer Aided Design and Manufacturing (lecture: 4, laboratory: 1) *

Integrated Manufacturing (lecture: 3, laboratory: 1)

(8) **University of Toronto**

At the University of Toronto, there is a Manufacturing Option offered in the Mechanical Engineering Department. This manufacturing option has been designed to provide students with a balanced knowledge across a spectrum of technical subjects including properties of materials, manufacturing fundamentals, automation, and production planning and control.

Manufacturing Engineering (lecture: 3, laboratory: 1.5, tutorial: 1.5) *

Robotics (lecture: 2)
Automated Manufacturing (lecture: 3, tutorial: 2)

Computer Aided Design (lecture: 2, laboratory: 2)

Manufacturing and Production Systems (lecture: 3, tutorial: 2) *

(9) University of Waterloo

The Department of Mechanical Engineering offers

Manufacturing Processes (lecture: 3, laboratory: 3) *

Advanced Manufacturing Technologies (lecture: 3, laboratory: 3) *

Kinematics, Dynamics and Control (lecture: 2, laboratory: 2)

Computer-Aided Design (lecture: 3, laboratory: 2)

Finite Element Methods (lecture: 3)

(10) University of Western Ontario

The University of Western Ontario makes a lot of efforts to enhance the manufacturing engineering education. Although there is no CEAB accredited manufacturing engineering program provided by the university at the moment, a manufacturing engineering option is offered by the department of Mechanical Engineering. Within this option, there are three choices: Manufacturing Engineering with Business, Manufacturing Engineering with Computer Science, Manufacturing Engineering with Economics.

Manufacturing Processes (lecture: 3, laboratory: 2) *
Finite Element Methods In Engineering (lecture: 2, laboratory: 2)  
Robotics and Manufacturing Automation (lecture: 2, laboratory: 2)  
Computer Numerically Controlled (CNC) Machining (lecture: 2, tutorial:2)  
Computer-Aided Design/Computer-Aided Manufacturing  
(lecture: 2, laboratory: 3) *  
Computer Integrated Manufacturing (CIM) (lecture: 2, laboratory: 2) *  

(11) University of Windsor  

The Department of Industrial & Manufacturing Systems Engineering offers:  
Manufacturing Technology and Processes (lecture: 3, laboratory: 2) *  
Computer-Aided Design and Manufacturing (lecture: 3, laboratory: 2)  
Fundamentals of Flexible Manufacturing Systems (lecture: 3, laboratory: 2)  
Statistical Methods in Manufacturing (lecture: 3, laboratory: 2)  

From the lists above, it can be seen that most universities in Ontario are providing manufacturing engineering related courses in their engineering programs. Some of them emphasize theory while the others focus on both theory and practice. A brief comparison of manufacturing engineering related courses in various Ontario universities is shown in Table 3.1 below.  

In Table 3.1, the time used for comparison is the lecture and laboratory hours per week during the semester as indicated in the syllabus of each university.
Table 3.1 Independent (Stand-alone) manufacturing related courses offered by different Ontario Universities

<table>
<thead>
<tr>
<th>Universities</th>
<th>Robotics*</th>
<th>Computer- Integrated Manufacturing</th>
<th>Manufacturing Engineering/ Manufacturing Process</th>
<th>CAD/CAM</th>
<th>Finite Element Analysis**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lecture (hrs per week)</td>
<td>lab (hrs per week)</td>
<td>lecture (hrs per week)</td>
<td>lab (hrs per week)</td>
<td>lecture (hrs per week)</td>
</tr>
<tr>
<td>Carleton University</td>
<td>3</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Lakehead University</td>
<td>3</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>McMaster University</td>
<td>3</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Queen’s University</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Royal Military College</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Ryerson Polytechnic University</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>University of Ottawa</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>University of Toronto</td>
<td>2</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>University of Waterloo</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>University of Western Ontario</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>University of Windsor</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

* In the universities shown in this table which do not offer a course in Robotics, this subject is taught as a part of courses in the Mechanical Engineering curriculum

** In the universities shown in this table which do not offer a course in Finite Element Analysis, this subject is offered as a part of a course in “Mechanics of Formable Bodies” or “Design of Machine Elements”.

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3.3 *Some observations and trends in Manufacturing Engineering Education in Ontario universities*

The above sub-section briefly summarized the manufacturing engineering education in Canada, in particular, in Ontario. Historically, Manufacturing Engineering has been a dynamic field in Canadian universities. Internationally, teaching manufacturing engineering has been carried out in many institutions and universities since the 18th century (Dwyer, 1997). With the advent of computer technology, more attention has been paid to manufacturing engineering education, especially in the field of computer-aided manufacturing and systematic manufacturing.

From reviewing the manufacturing related courses in Ontario universities, we can see that they have made lots of efforts to integrate the advanced manufacturing engineering technologies into their curriculum. Table 3.1 shows that ten out of eleven universities provide a course in CAD/CAM. Some of them have independent CIM, Finite Element Analysis or Robotics courses. These courses are taught as part of the Mechanical Engineering curriculum in most universities except the University of Windsor. Located on the U.S. border, adjacent to major facilities of the big three automobile companies, the University of Windsor has had a focus on the manufacturing engineering domain for a long time. The University set up the Industrial Engineering department in 1974 (CEAB annual report, 1998). During the past 16 years, the department has established close ties with the local manufacturing enterprises and educated many graduates for their technical personnel needs. In the next chapter, we will present a study of the status of
manufacturing engineering education in Windsor, and propose a model for developing the CIM laboratory from its existing facilities in a cost-effective way.

Among the eleven Ontario universities which have engineering programs, there are three which provide Manufacturing Engineering programs. McMaster University established the first CEAB accredited Manufacturing Engineering program in Canada in 1982. Since then, the university worked ceaselessly and started to provide the two CEAB accredited programs named “Manufacturing Engineering and Management” and “Manufacturing Engineering and Society” in 1998. At the University of Western Ontario, although there is still no CEAB accredited manufacturing engineering program, the Mechanical Engineering Department of the university provides a manufacturing engineering option. Within this option, students have three choices: Manufacturing Engineering with Business, Manufacturing Engineering with Computer Science, and Manufacturing Engineering with Economics. University of Toronto has a manufacturing engineering option too. It is designed to provide students with the knowledge of manufacturing fundamentals, automation, and production planning and control.

Based on these observations, we find that providing manufacturing engineering programs or options in an engineering department has become a trend in Ontario universities. The location of the programs within a Mechanical Engineering department is quite appropriate. The practical experience of the above three universities proved that these programs attract lots of students and the capability of the graduates can satisfy the industrial need for this type of enterprise. However, with increasing requirements and
challenges arising from a broadening of the roles that engineers will play in the future as section 2.4 indicated, engineering faculties of Ontario universities need to make more progress in their manufacturing engineering programs in order to support and maintain success in the global market. As table 2.2 indicated, the CIM systems being used in manufacturing enterprises will increase from 27% current usage to 57% required usage in the new millennium. Given this trend, the improvement in manufacturing education should aim to provide engineering students more exposure to the complex and integrated features of modern manufacturing systems, and to practice the concepts and theories learned in the classroom. How to achieve this goal in a cost-effective manner is of concern.

In addition, as outlined in section 2.3 and 2.4, manufacturing engineering is, in today's global environment, a complex multi-disciplinary activity; it is no more a simple reflection of the traditional metal cutting operations of the 1950's, 60's and 70's. A Manufacturing Engineering program requires inputs not only from traditional Mechanical Engineering, but also from Industrial Engineering, Electrical Engineering, Management Science and Economics, and from other disciplines. Given this focus, it is not necessary that manufacturing engineering be a separate department as is traditionally found in Europe (Reference section 2.2). However, given its inter-disciplinary characteristics, the program proposed in this thesis in chapter 4 would be an effective way of providing this program, while at the same time ensuring that it is reasonably cost-effective and easy to implement.
3.4 Program and Curriculum Quality Control

The Canadian Council of Professional Engineers (CCPE) was established in 1936 as the federation of the provincial and territorial authorities which license engineers and oversees the engineering profession across Canada. In 1965, CCPE established the Canadian Accreditation Board (CAB), now known as the Canadian Engineering Accreditation Board (CEAB), to accredit Canadian undergraduate engineering programs and ensure that they meet or exceed the educational standards acceptable to the profession in Canada. (Accreditation Criteria and Procedures, 1998)

The Engineering curriculum accreditation process and criteria will have a significant influence on the academic development of engineers in the 21st century. CEAB plays an important role in Canada. As with other organizations, CEAB has noticed the challenge facing engineering education for the next century. In its 1998 annual report, it was stated that “it is clear, however, that the engineering graduates of today must be poised to take an appropriate leadership role in a future likely to be dominated by information technology”. Therefore, the manufacturing engineering curriculum should emphasize the idea that manufacturing engineering is not just a transformation of raw material into a finished product, but rather is becoming increasingly a transformation of knowledge and data in the context of computer integrated manufacturing (CIM).

The CEAB also makes the point that engineering graduates must be “adaptive, creative, resourceful, and responsive to changes in society, technology, and career
demands” so that they can meet the requirements of the future. Furthermore, CEAB recognizes the increasing interdisciplinary nature of technology demands; hence engineers should receive a broad education. “The curriculum should include engineering science content which imparts an appreciation of important elements of related engineering disciplines” while preventing “overspecialized curricula”.

The purpose of accreditation is to identify to the constituent members of the CCPE those engineering programs that meet the criteria for accreditation. These criteria are formulated to provide graduates with an education satisfying the academic requirements for registration.

The criteria for engineering curriculum content assure an adequate solid foundation in mathematics and basic sciences, a broad preparation in engineering sciences, and engineering design, and an exposure to non-technical subjects that complement the technical aspects of the curriculum. "Appropriate laboratory experience must be an integral component of the engineering curriculum in CEAB accreditation criteria. Major importance is attached to the quality of the educational experience as reflected by the quality of the students, the faculty, the support staff, the administration, the laboratories, the library, the computing facilities and other supporting facilities." (Canadian Engineering Accreditation Board (CEAB) Annual Report, 1998)

Engineering faculties in Canada have been undergoing accreditation of their programs for over thirty years. The CEAB publishes yearly revised guidelines for
accreditation. Questionnaires are answered by the interested engineering department, and sent to the CEAB. This is followed by the site visit, where the CEAB team examines the curriculum, laboratory, computer and library facilities, and performs interviews with the faculty, students and staff.

The CEAB listings include only engineering programs which lead to a bachelor's degree. In CEAB's year annual report, accredited manufacturing engineering related programs are as followings:

MANUFACTURING ENGINEERING

Calgary: 1997-present

McMaster: 1982-present

MANUFACTURING ENGINEERING AND MANAGEMENT

McMaster: 1998-present

MANUFACTURING ENGINEERING AND SOCIETY

McMaster: 1998-present
CHAPTER 4 – INTEGRATING MANUFACTURING ENGINEERING EDUCATION INTO THE UNDERGRADUATE ENGINEERING CURRICULUM

In the last chapter, the manufacturing education in Ontario was reviewed. From reviewing the manufacturing related courses provided by Ontario Universities, we found that they cannot give students enough hands-on experiences and a complete understanding of the integrated feature of the manufacturing system. In order to solve these problems, a proposal of integrating manufacturing engineering content for undergraduate engineering courses through a CIM laboratory is presented in this chapter.

4.1 What is CIM?

The term Computer Integrated Manufacturing (CIM) was coined by Dr. Joseph Harrington in 1973 to describe the logical direction for growth of the manufacturing enterprise (Shrensker, 1990). He claimed that manufacturing enterprises should utilize the interrelationships between the various functional areas and integrate them through computers in order to increase the efficiency and effectiveness of the organization. CIM has been defined in many ways. Shrensker (1990) gave one of the most inclusive definitions.
According to Shrensker's definition, CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency. The CASA/SME CIM Wheel is often cited as a diagrammatic representation of this comprehensive definition. It ties dimensions such as general business management, product and process definition, manufacturing planning and control, factory automation, and information resources management together. The relationship between these dimensions is shown in Figure 4.1 (Shrensker, 1990; Veilleux and Petro, 1991)

Figure 4.1 CASA/SME CIM Wheel

(Copyright 1990, Society of Manufacturing Engineers, Dearborn, MI)
Other definitions of CIM have a common thread running through them in which CIM is viewed as a concept that facilitates the control of all phases of the manufacturing cycle through integrated systems (Groover, 1990; Mitchell, 1991; Kusiak and Heragu, 1988). The National Research Council concludes that CIM has occurred when all the processing functions and related managerial functions are expressed in the form of data that may be generated and manipulated through computer technology throughout the entire enterprise (Mitchell, 1991).

With the feature of “bringing everything together”, a simplified representation of a computer integrated manufacturing enterprise is shown in Figure 4.2. It indicates that the principle of CIM is the accessibility to all information pertaining to a product's manufacturing by all functions that impact upon it. This accessibility is achieved through the "information ring" surrounding the area labeled "Process Automation and Technologies". The related issues here are the databases of all information concerning the product and its manufacture, integration of all the functional areas, and the implementation of networks to establish internal and external links within the organization, or with vendors and/or clients.
Figure 4.2. Simplified Representation of a CIM Enterprise
4.2 Educational Strategies in CIM

The uniqueness of individuals causes the mechanics of social interaction to be very complex. What interests or is valued by one individual may not hold true for another. Therefore, it is desirable to develop teaching methods to fulfil the needs of different types of students.

From the definition of the word "teach" it may be seen that this activity is truly completed when students have learned to process information at higher/deeper levels of thought. This is a gradual process in learning and teaching. In his work on developing a taxonomy for educational objectives, Bloom (1971) sought to design a taxonomy to be a classification of student behaviors which represent the intended outcomes of the educational process. The cognitive taxonomy has six major classes arranged in a hierarchical order from simple to complex, from abstract concepts to reality practice, and these are as listed below.

1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation
To summarize, at the knowledge level, the students are required to be able to recall material without actually using or understanding the same in detail; the processing required of the student is thus passive in nature. Intermediate levels include comprehension and application and require some understanding of the application of material without seeing or understanding all the implications, or the use of abstraction in particular and concrete situations. At the higher levels - analysis, synthesis, and evaluation, students are required to recognize and assimilate the organization of thought processes related to communication on a given theme, work with bits and pieces of information to develop a coherent whole, and make quantitative and qualitative judgements about the extent to which material and methods satisfy the criteria (Bloom, 1971; Neal, 1991).

Therefore as one moves from knowledge at the first level, through the intermediate levels of the domain, to evaluation at the final level, the depth of processing required of the student increases. At higher levels, reasoning processes result in better understanding and mastery of the subject. The traditional textbook/lecture/recitation format would thus result in low-level processing on the part of students. While in this particular case experiments and projects based on a CIM laboratory would require the highest levels of processing on the part of the students using the facility. Learning accomplished in this manner would be the most effective.

Neal (1991) reported a phenomenon that most educators have seen at one time or another - students with marked preferences for either structured laboratories or individual
projects or group projects etc. In the areas of laboratory activities related to manufacturing in general and CIM in particular, various assignments centered around the laboratory would address and attract different personality types. In order to enrich the learning experience, the instructor should be prepared to develop a portfolio of courses based on the laboratory activities that would stimulate, and be of interest to the various personality types.

The importance of laboratories in manufacturing engineering education is an issue that has been discussed extensively (Mufti and Graham, 1992). Laboratories provide invaluable support for the students to understand the various aspects of a functional area. In the field of manufacturing they provide the physical link between concepts and the application of various tools for the development and manufacture of products. Thus, CIM laboratories act as a bridge to fill the trenches between the theory and the skills that are expected in industry. A computer learning laboratory coupled with an integrated manufacturing system is helpful for students to establish the relationships between CAD, manufacturing planning activities like process planning, and manufacturing control activities such as shop floor control via a monitoring workstation.

The training in the CIM laboratories should be organized for undergraduate students from two departments - Mechanical Engineering (ME) and Industrial and Manufacturing Systems Engineering (IMSE). CAD is being integrated more into the ME Curriculum, while CAM programming resides in the Department of IMSE. ME students are oriented for a particular production sphere - mechanical engineering, instrument
engineering. They are trained as technology engineers, designers, commissioning and adjustment experts, and production/control engineers, who should master professional techniques of using the entire scope of modern science and technology to obtain a material result, be it a particular product or its parts. The IMSE students are trained as management experts taught to master general tools and techniques for design, management, and control of different levels of CIM. They are trained as system engineers and analysts with a thorough knowledge in all production perspectives. (Edan and Livshitz, 1997)

In the CIM laboratory, students can use advanced automation facilities such as CNC machines and robots programmed to manufacture simple products (Edan and Livshitz, 1997). The student's operations and products constitute the major factors in the creation of a future expert. Through industry-based CAD/CAM projects and exercises provided by the CIM laboratory, students not only obtain the knowledge and technologies but also master the analysis, synthesis ability for Computer Aided Design, Engineering and Manufacturing systems.
4.3 *Basic Functions which should be supported by a CIM Laboratory*

It is very important for the ME and IMSE departments to prepare engineers to work with computers and automated manufacturing technologies. Thus, the goals of the CIM laboratory are to allow:

- Students to be able to integrate computers with manufacturing operations;
- Students to carry out independent and group projects to maximize the capabilities of the laboratory;
- Expanded coverage of CIM concepts throughout the curriculum;

At the same time, the CIM laboratory should allow:

- Faculty to develop their expertise in CIM and to carry out research projects;
- Industry in cooperation with Faculty of Engineering to use the facility for continuing education and training courses;
- Industry in cooperation with Faculty of Engineering to collaborate with faculty on research projects.

The CIM laboratory is designed to simulate the functions and processes carried out in a typical manufacturing enterprise. W. Evelles (1994) listed five functions that should be supported in a CIM laboratory: business planning; product design; process
planning; product manufacturing; and production planning and control. Figure 4.3 contains a data-flow diagram to illustrate the relationships between these five functions and the databases. The five functions are represented as rounded corner rectangles, the data inputs and outputs as arrows, and the major components of an integrated database as squared corner rectangles.

These functions are similar to those contained in the Computer and Automated Systems Association/Society of Manufacturing Engineers (CASA/SME) CIM wheel (Thacker, 1989). They have been modified to reflect the educational needs of the students and the ability to perform the activity in a laboratory environment. In the laboratory, product ideas originate from the customer requirement to form student projects or research projects. Students and faculty develop these ideas into product designs, process plans, and automated production systems.

Business planning involves three supportive activities: demand forecasting, customer billing and accounting/finance. The results of these activities will eventually be stored in an integrated database and will be available for product design and process planning activities.

Product design involves three primary activities: designing of a product, analysis of the design, and building of a prototype. The first two activities are software oriented. Students can use computer aided design (CAD) software to develop a preliminary product design. Then the design is modeled 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, modeling, and testing is carried out easily. In this stage, students should learn: Computer Aided Design/Drafting, Facility Design/Plant Layout, Design for Manufacturing and Group Technology.

Process planning involves developing and testing the process plan via computer simulation to determine both its effectiveness and cost. Developing a process for a given product design involves 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 a series of process designations. Once the process plan is complete, a manufacturing bill of materials is created for use in the production planning and control activities. Students should master the skills of cost estimating, Computer Aided Process planning, and scheduling through this function.

Product manufacturing involves three primary activities: programming the process components, integrating and controlling the components, and testing the production systems. These activities are 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.
Figure 4.3 The relationship between the functions and the databases that will be integrated in the CIM laboratory environment.
by adding sensing devices and programs to control the flow of materials through the system. The activity culminates with actual tests of the production system and the recording of the kinds of capabilities that can be expected from the CIM system. Students are expected to learn NC part programming and how to transfer the programs from computers to CNC machines.

Production planning and control involves four activities: scheduling production, planning materials, monitoring work orders and monitoring purchase orders as they are processed by the vendors. The production planning and control activities are difficult to include in the laboratory, since the laboratory is not an actual production environment. However, studies in this area can be undertaken using "simulated" production requirements and software for production planning and control.

The five functions listed above constitute the infrastructure or the information-processing ring around the physical operations that happen on the shop floor. Various definitions of CIM have addressed the flow of information right from the time where a customer places an order up to the point where the finished goods are shipped out of the factory. For academic institutions, the aim is, ideally, to have the same infrastructure in their laboratories with the complete sharing of information across the functions of business, design, planning, production, and control.
4.4 CIM laboratory models and development methods

Because of the differences in institutional missions, capabilities, and budgetary constraints, it is not surprising that the results vary considerably from one to another institution during the laboratory development process. In this field, our neighbour, the United States, has carried out significant work. Many institutions in the United States have launched CIM initiatives supported by laboratory facilities over the past few years (Omurtag, 1992). Also, different kinds of CIM laboratories have been established in some institutions around the world. Their experiences are good reference points for Canadian engineering schools.

A couple of models have been developed in the past. For example, various types of advanced independent stand-alone (manufacturing scale) automation cells (CNC, assembly, FMS e.g.) have been established by the ME or IMSE departments at the University of Wisconsin, Madison, Purdue University and the National University of Singapore. Other approaches were based on educational automation modules (toy-like) connected in a CIM configuration (these systems do not provide actual production experience) or specific configured systems dedicated to particular research (but quite limited as an educational tool for the various aspects of CIM). (Bauder et al., 1991) Yael and Victor presented a "microplantization" approach to their students who were exposed to technological aspects through actual production on scaled-down industrial machines (Edan and Livshitz, 1997).
The CIM laboratory should be designed as a "computer integrated" environment, so students can be exposed to an environment similar to that of the real shop floor. According to Erevelles (1994), there are four primary levels of integration in a CIM laboratory: stand alone equipment, islands of integrated equipment, integrated machining/assembly system and integrated manufacturing system with information exchange. Each school can decide the level of integration to incorporate within its CIM laboratory based on resources available.

Integration of an educational CIM laboratory may be achieved through various means. At the outset, an integrated turnkey system may be a viable solution if the proposed laboratory lacks equipment and technical support. If the proposed CIM laboratory has stand-alone machines, other equipment and adequate human resources, a good facility may be built either by writing the software in-house or purchasing commercial software. Each method has its advantages and disadvantages; the best "fit" needs to be assessed on a case by case basis.

The most frequent type of methods being used for CIM laboratory development is acquisition of system components and integration using software written in-house (Erevelles, 1994). It can satisfy customization requirements and be more readily upgraded. However, this approach requires sufficient qualified technicians. Acquisition of system components and integration using commercial software is an alternative chosen by many universities, because this method provides a fast way for the schools to implement a CIM laboratory, but it is difficult to upgrade. Acquisition of a complete
system from a single vendor (turnkey solution) is rarely used due to budget constraints. Some of the universities use a combination of the above methods to develop their CIM laboratory.

Whatever approach the industrial and mechanical engineering schools choose to develop their CIM laboratory, the laboratory requirement may be met by fund raising or pairing with industry. The department may request internal funding from its college and from the university. The external-funding activities may be initiated if the internal funding is not enough or unavailable. Another alternative is that the department may use its industrial contacts with local industries and work out a plan.

A university/industry partnership is adopted to facilitate university-industry collaborative research by many universities in North America. This pattern can greatly contribute to technology/knowledge transfer and educational relevance through graduate and undergraduate co-operative programs/industrial internships, joint research/laboratory facilities, and active industry participation in curriculum development and delivery. Thus, universities can use it as a reference for the CIM laboratory development.

During the collaboration, universities should keep in mind that the university/industry partnership should not aim only for the "best deal" for themselves but for a successful research program and relationship while maintaining the integrity and objectives of each participant. A Government-University-Industrial Research Roundtable report (1996) pointed out: "The primary value of the [university/industry]
relationship is in new knowledge generated by the research that benefits the university, the company, and the public, with the added value of training students to understand industrial problems." If both parties of the partnership can keep this in mind, potential conflicts may be more easily resolved.
4.5 Recommended Teaching Levels within a CIM laboratory

Section 4.2 refers to a cognitive taxonomy which has six major classes to represent the intended outcomes of the educational process arranged in an ascending order of reality. In teaching levels that are associated with different elements of a CIM laboratory, it is easy to conceive of a continuum of teaching techniques that would operate along similar lines. Figure 4.4 depicts five such teaching levels for the purpose of this research.

![Diagram showing hierarchy of teaching levels]

Figure 4.4 Hierarchy of teaching levels

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It is obvious that these levels are linked to a continuum of instructional methods ranging from the highly abstract to the very real. The hierarchy itself does not need any explanation. What it does is to establish visible and definable ranges of instruction for a given element in a CIM laboratory. The levels that have been specified may be used to define the minimum criterion at which instruction in a particular area can be constructed effectively.

In academia, like in industry, the planning for CIM laboratory development is vital to the success of the project. Veilleux and Petro (1991) provided several items in the form of a checklist (Table 4.1). The author strongly recommends the usage of this checklist in the development of CIM laboratories.

Table 4.1: Recommended Teaching Levels for Necessary Elements in a CIM Laboratory. (Veilleux and Petro, 1991)

<table>
<thead>
<tr>
<th>Element</th>
<th>Minimum Recommended Level of Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Forecasting</td>
<td>Computer Simulation</td>
</tr>
<tr>
<td>Communication Networks</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>Systems Integration Software</td>
<td>Commercial Software, Developed in-house etc.</td>
</tr>
<tr>
<td>Database Management</td>
<td>Industrial Grade software</td>
</tr>
<tr>
<td>Group Technology</td>
<td>Theory/Simulation/Physical Modeling</td>
</tr>
<tr>
<td>Facility Design</td>
<td>Simulation, CAD Software, and Physical Models</td>
</tr>
<tr>
<td>Design for Manufacturing</td>
<td>Scaled Hardware and Software</td>
</tr>
<tr>
<td>Process Design</td>
<td>Scaled Hardware and Software</td>
</tr>
<tr>
<td>CAE</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>CAD</td>
<td>Scaled and Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>Scheduling</td>
<td>Commercial Shop Floor Control Software</td>
</tr>
<tr>
<td>Cost Estimating</td>
<td>Commercial Shop Floor Control Software</td>
</tr>
<tr>
<td>Material Requirement Planning</td>
<td>Commercial Shop Floor Control Software</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Computer Aided Process Planning</td>
<td>Commercial Shop Floor Control Software</td>
</tr>
<tr>
<td>NC Part Programming</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>Diagnostics/Error Recovery</td>
<td>Conceptual/Simulations, use actual system if possible</td>
</tr>
<tr>
<td>Shop Floor Control</td>
<td>Commercial Shop Floor Control Software</td>
</tr>
<tr>
<td>Process Monitoring and Process Control</td>
<td>Scaled Equipment leaning towards Industrial Grade</td>
</tr>
<tr>
<td>Computer-Aided Inspection and Testing</td>
<td>Scaled Equipment leaning towards Industrial Grade</td>
</tr>
<tr>
<td>Adaptive Control</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>Automated Storage and Retrieve System</td>
<td>Scaled Equipment with Industrial Grade features</td>
</tr>
<tr>
<td>Automated Assembly</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>Automated Material Handling</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>Flexible Manufacturing Cells</td>
<td>Scaled Equipment with Industrial Grade features</td>
</tr>
<tr>
<td>Numerical Control and Direct/Distribute NC</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>CNC</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>Machine Vision</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>Metrology</td>
<td>Scaled Equipment</td>
</tr>
<tr>
<td>Robotic Operation in Manufacturing</td>
<td>Scaled Equipment with Industrial Grade features</td>
</tr>
</tbody>
</table>
4.6 Preliminary plan for the establishment of the CIM laboratory

In 'the automotive capital of Canada', on the U.S. border, the University of Windsor offers manufacturing courses through the Industrial & Manufacturing Systems Engineering (IMSE) programs. The university, in its current Mission Statement, has recognized manufacturing as one of four areas of focus. The proposal for a new Ph.D. Program in Manufacturing Systems Engineering was successful in the OCGS (Ontario Council of Graduation Studies) accreditation process and commenced in 1995 (ElMaraghy and ElMaraghy, 1998).

In order to achieve the mission, the University of Windsor had established a Machine Automation Research (MAR) Laboratory and three Intelligent Manufacturing Systems (IMS) Laboratories. The MAR Laboratory is located in Essex Hall Room B20 and Room 230. It is supported and funded by the Natural Sciences and Engineering Research Council of Canada (NSERC); Manufacturing Research Corporation of Ontario (MRCO); Ford Motor Company (Powertrain Operations); Delphi (GM) U.S., Delphi (GM) Mexican; Peregrine Engineering Inc.; and Reko International Group Inc. The equipment in the MAR Laboratory includes:

- A Cincinnati Milacron Arrow 500 vertical milling machining centre
- Data acquisition system (4 channels at sampling frequency of 500 kHz)
- PRAFF industrial sewing machine
- Kistler Dynamometer for three dimensional force measurement
• Accelerometers and displacement transducers for vibration measurement

• Computer Workstations, PCs

• CAD/CAM software (I-DEAS, ANSYS, Cimatron, CIMLINC, VeriCut, Labview, MATLAB)

The three Intelligent Manufacturing Systems Laboratories are: IDM (Integrated Design and Manufacturing) Laboratory, located in Essex Hall Room 307. The FMR (Flexible Manufacturing and Robotics) Laboratory, located in Essex Hall Room 305, and the AMR (Advanced Manufacturing Research) Laboratory, in Essex Hall Room B24.

Hardware in these laboratories include:

• Experimental modular link (flexible, rigid or composite) robot and controller

• BOSCH conveyor system, assembly cell with VME Control system

• Adept SCARA Robot (in cell)

• PUMA 560 Articulated Robot (in cell)

• Comau 60 and Smart S robots

• D-Space Real-time computer for high-speed control

• Experimental flexible joint robot and controller

• Network of 20 SUN SPARC + 1 SGI Crimson, and 3 Indy workstations with several PCs.

• Colour and monochrome laser printers

• Flatbed Greyscale & Colour Scanners

• UPS serviced Server Room (307A) with SUN 670MP and 470 Servers and 8mm tape backup system
• Vision System and laser equipment
• Laser, force, torque and tactile-array sensors

Software in the three IMS laboratories includes:
• Expert system software - Kee, Simkit, Nexpert, PCPlus
• Geometric Modelling and engineering analysis s/w - I-Deas, Acis, Parasolids, Nastran
• Manufacturing simulation software - Siman, cinema, fmx, CIMstation
• Programming and Graphics Tools - C, C++, FORTRAN, PHIGS, HOOPS
• Desktop Publishing software - FrameMaker, Interleaf
• Analysis tools - Matlab, Xmath, Matrix/x
• Symbolic Algebra - Maple, Macsyma, Mathematica

In addition, books, journals and conference proceedings are available in these laboratories. Currently the MAR Laboratory and the IMS Laboratories are primarily used for Research and for Robotics and Manufacturing courses for the ME and IMSE graduate students. The facilities are located in different locations of the Essex Hall. From the author's viewpoint, the preliminary establishment of a CIM laboratory at the University of Windsor can start with existing equipment available in the university.

The basic elements of a CIM laboratory are: CNC machine; personal computers (PC); automatic storage and retrieval system (AS/RS) and CAD and simulation packages. Based on the hardware integration approach, the first step in establishing a CIM laboratory is to build blocks called 'robot cells' or 'islands of automation', which are then
assembled into a manufacturing configuration (Kuttner, 1986; Zeid, 1998). Each cell consists of a machine tool, one or more robots, inspection devices, and a 'bus interface unit' for connection to the rest of the network. Obviously, by this approach, a CIM laboratory can be readily made from existing equipment, and easily updated. Furthermore, a CIM laboratory can fulfil various purposes by different combinations of the cells. The laboratory established by this approach "fits" the second integrated level, islands of integrated equipment, classified by Erevelles (1994) in the above sub-section.

For the University of Windsor, the preliminary CIM laboratory may start out with several stand alone machines such as a CNC machine tool, a robot, and a rapid prototyping machine, then proceed to integrated manufacturing cells, and finally form a total integrated system. With the existing facilities a flexible-machining cell can be established as a start to include:

- Cincinnati Milacron Arrow 500 vertical milling machining centre
- Data acquisition system
- Experimental modular link (flexible, rigid or composite) robot and controller
- BOSCH conveyor system / assembly cell with VME Control system
- Vision System and laser equipment
- Personal Computers and printers
A blueprint of the flexible-machining cell is shown in figure 4.5.

Figure 4.5 The layout of the flexible-machining cell
4.7 The courses that can benefit from the CIM Laboratory

The development of the CIM laboratory can benefit not only manufacturing courses such as Manufacturing Technology and Processes, CAD/CAM but also mechanical courses such as Kinematics and Dynamics, Mechanical Vibrations, and Heat Transfer. This will help the students obtain much hands-on experience and acquire a full understanding of the integrated feature of the manufacturing system.

Three main categories of courses: mechanical design, dynamic systems, and thermal sciences in the Mechanical Engineering curriculum will benefit through the CIM laboratory, which include:

- Machine Design
- Kinematics and Dynamics
- Heat Transfer
- Mechanical Vibrations
- Control Theory
- Computer Aided Analysis Tools

The courses of the Industrial Engineering department which would benefit include:

- Manufacturing Technology and Processes
- Simulation of Industrial System
- Material Handling Analysis
- Computer Aided Design and Computer Aided Manufacturing
The program proposed in this thesis will not require the addition of any new courses, which would be difficult given the time constraints and faculty availability. Instead, the author looks for a way to teach students with modern manufacturing technology through enhancement of manufacturing engineering content in existing courses by using the CIM laboratory.

For instance, the University of Windsor provides CAD/CAM, a course covering fundamental concepts in computer-aided design, numerical control of machine tools, computer-aided manufacturing, computer-aided process planning, group technology, robotics and their applications, and Flexible Manufacturing Systems. Without the CIM laboratory, most topics in this course can be taught in the traditional way, i.e. giving classroom lectures about the theories and mathematical models. The laboratory support to the class in the traditional approach is not incorporated in an integrated manner. As mentioned in section 4.6, the facilities are scattered among different laboratory in the University of Windsor, and different laboratory use various kinds of software. This cannot give students a good view of the complex and the integrated features of the manufacturing system. However, the higher teaching levels in Table 4.1 will be achieved with the help of the proposed CIM laboratory (see Table 4.2 on page 75). As shown in figure 4.5, with the establishment of the flexible-machining cell, students can practise the knowledge they learned from the topics of Computer Numerical Control and Automated Programming Tool language on the CNC milling machine. Giving the students a project to make actual parts in the flexible-machining cell, they can manipulate the robots and

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conveyor. This experience will deepen understanding of CAPP, MRP and CAM. These exercises will help provide the students with an understanding of the concept from CAD-CAM to FMS and CIM. A CIM laboratory, using industrial grade software, simulates the conceptual framework of each subject in the real world of manufacturing. According to the CAD/CAM, CAE survey, review and buyer’s guide (1999) (Reference source: http://www.daratech.com), the software available for the academic laboratory fifteen years ago was for general purposes and was difficult to use. However, in the last five years, software has been tailored to the CIM laboratory environment and hardware and it is available at a reasonable price for the manufacturing education arena. This software is more user-friendly for students to master. Industrial grade software packages such as IDEAS™, CATIA®, Pro Engineering®, or Unigraphics™ are suitable for CIM laboratories.

Before further discussion on integration of the courses, let us first view the university as a production system (Figure 4.6) to determine how to produce graduates to satisfy the requirements of the “customers” through the program. Then we examine how the manufacturing engineering content can be improved in the other undergraduate engineering courses through the CIM laboratory.
Figure 4.6 Illustration of the CIM laboratory related courses integrated into The ME and IE departments.
Table 4.2. Comparison of teaching levels with or without CIM lab for a typical CAD/CAM course

<table>
<thead>
<tr>
<th>Topics</th>
<th>Teaching levels without CIM lab.</th>
<th>Teaching levels with CIM lab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to and development of CAD-CAM</td>
<td>Theory</td>
<td>Theory</td>
</tr>
<tr>
<td>Hardware and Software for CAD, 3-D modelling</td>
<td>Theory and Mathematical Modelling</td>
<td>Theory, CAD software</td>
</tr>
<tr>
<td>Finite element method</td>
<td>Theory and Mathematical Modelling</td>
<td>Theory, Physical Modeling, and CAD software</td>
</tr>
<tr>
<td>Numerical Control, Direct Numerical Control</td>
<td>Theory and Mathematical Modelling</td>
<td>Theory and Mathematical Model</td>
</tr>
<tr>
<td>Computer Numerical Control</td>
<td>Theory and Mathematical Modelling</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>APT (Automated Programming Tool) language, part programming</td>
<td>Mathematical Modelling</td>
<td>Industrial Grade Hardware and Software</td>
</tr>
<tr>
<td>Robotics and applications</td>
<td>Theory</td>
<td>Scaled Equipment with Industrial Grade features</td>
</tr>
<tr>
<td>Group Technology</td>
<td>Theory</td>
<td>Theory, Simulation, and Physical Modelling</td>
</tr>
<tr>
<td>CAPP and MRP (Material Required Planning)</td>
<td>Theory and Mathematical Modelling</td>
<td>Simulation</td>
</tr>
<tr>
<td>Integration of CAD with CAM-justification</td>
<td>Theory</td>
<td>Scaled Hardware and Software</td>
</tr>
<tr>
<td>From CAD-CAM to FMS and CIM</td>
<td>Theory</td>
<td>Scaled Equipment with Industrial Grade features</td>
</tr>
</tbody>
</table>
The topics in computer graphics can be introduced through the junior-level course in kinematics. This course is an obvious choice because kinematics is visually oriented and the use of animated computer graphics demonstrates the insight which CAD methods can provide in the solution of engineering problems. This course will introduce the student to some of the capabilities of CAD. The CIM laboratory will provide facilities such as computer hardware and required CAD. Students are not required to generate graphics-oriented programs at this stage. This procedure will provide the opportunity for the student to realize the potential of computer-aided design without the burden of generating detailed programs.

Machine Design is the second course in the design sequence. In this course, instruction may be provided in modelling techniques and the use of commercially available finite element programs for the analysis of mechanical systems. Different universities can buy the commercial computer-aided design and analysis program packages such as I-DEAS for beams, shafts or other structural elements according to their needs. Students would then have the chance to use different software programs to meet specific objectives.

In the dynamic systems sequence courses such as Dynamics and Vibrations, initial experience can be obtained in the simulation of dynamic systems using numerical techniques for the solution of the differential equations. At a later stage, these same techniques can be applied to the solution of vibration problems.
The experience in finite element analysis methods obtained in Machine Design can be transferred to the finite element methods used in the analysis techniques for heat transfer problems. In the course of Heat Transfer, conduction as well as conduction/convection problems are amenable to solution by finite element methods. Graphical presentation of such analyses enhances the learning effect by providing a more detailed and visual solution. Some of the same thermal analysis methods can be utilized in a laboratory. The CIM laboratory should provide the facilities for the students to utilize computer aided techniques for the analysis of experimental data.

The other possible use of the CIM lab is the senior-year design project and the Computer-Aided Design and Computer-Aided Manufacturing course. Many engineering schools require the students to solve a real world design/manufacturing problem. Students can use the facilities in the laboratory to solve the problem. When managed properly, it can not only create important ties between the universities and the industry, but also generate much needed positive cash flow.

In order to gain the maximum benefit, it is desirable to introduce students to the CIM lab as early as possible. Also, it is suggested that any computer aided design course is offered in the first part of the 3rd year. In this way, the CIM lab can be used firstly as a design tool, secondly as analysis tools and testing beds. It should be pointed out that integrating the CIM lab into the curriculum is not to create new courses in the existing program. Instead, it aims at strengthening the manufacturing component in the existing courses to benefit the curriculum to its maximum extent.
4.8 Comparison of the proposed program with the CEAB Accredited program

As mentioned in section 3.4, McMaster University and the University of Calgary are the two universities that have the CEAB accredited manufacturing programs in Canada. A review of their curricula (see Appendix) found that the subjects are taught in separated and distinct units instead of in an integrated modular manner. In the program proposed in this thesis, some subjects are taught in an inter-connected module within the framework of the proposed CIM laboratory (refer to figure 4.6). The above section has presented the detail of how to integrate these subjects within the CIM laboratory. These subjects are also provided in the Manufacturing Engineering programs of McMaster University and the University of Calgary as Table 4.3 shown.

Table 4.3 The suggested courses that can be taught in an inter-connected module through the CIM laboratory

<table>
<thead>
<tr>
<th>Manufacturing Engineering courses McMaster University</th>
<th>Manufacturing Engineering courses University of Calgary</th>
<th>Manufacturing Engineering courses Proposed program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics of Mechanism</td>
<td>Kinematics and Dynamics of Machines</td>
<td>Kinematics and Dynamics</td>
</tr>
<tr>
<td>Heat Transfer</td>
<td>Integrated Manufacturing Systems</td>
<td>Heat Transfer</td>
</tr>
<tr>
<td>Manufacturing Engineering</td>
<td>Modelling and Simulation of Manufacturing Systems</td>
<td>Simulation of Industrial System</td>
</tr>
<tr>
<td>Computer-Aided Manufacturing</td>
<td>Manufacturing Engineering Design Methodology and Application</td>
<td>Computer-Aided Design and Computer-Aided Manufacturing</td>
</tr>
</tbody>
</table>
From the above table, it is obvious that the core courses of these programs are similar. As mentioned in section 3.4, the courses in the first two years of the engineering programs are to assure the solid foundation in mathematics and basic science, and to prepare for the further study by the CEAB criteria. Therefore, the proposed program can fulfil the CEAB requirements as at the other two universities (Reference Appendix II for a brief description of the course content). Moreover, the proposed program uses an integrated approach between these courses through the CIM laboratory to demonstrate many of the characteristics.
CHAPTER 5 – CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

Manufacturing engineering courses play an important role in modern mechanical engineering and industrial engineering education. However, unlike the basic science and engineering design courses which emphasize concepts, theories and design, a manufacturing engineering course stresses practice. Thus, the latter should be taught with a balance of theory, computer simulation and hands-on experience.

A curriculum to prepare qualified graduates to meet requirements of the industry must have a multi-disciplinary focus. This thesis presents the idea of integrating the manufacturing engineering content into the disciplines of Mechanical Engineering or Industrial Engineering with a Computer Integrated Manufacturing (CIM) laboratory. The proposed program aims to develop a more integrative and cross-disciplinary educational curriculum that will match the present and foreseeable needs. The establishment and development of the CIM laboratory should be used to promote academia-industry cooperation. This includes design projects, prototyping, as well as research and development projects.

Traditionally, laboratory exercises to support manufacturing engineering curricula tended to be machine shop oriented with emphasis on the training of students in the proper operation of lathes and milling machines in conjunction with design and
manufacturing courses. The use of the CIM laboratory as outlined in this thesis tries to
support integrating the advanced design and manufacturing knowledge such as
CAD/CAM and CIM into the ME/IE programs. In addition, the CIM laboratory makes a
valuable contribution to undergraduate training by providing a continuous source of
undergraduate projects, and the facilities in which to conduct them, to the various
departments. Through the CIM laboratory, students also obtain an opportunity to access
the latest machines (e.g. CNC machines and robots) and technologies so that they can
master the state-of-the-art technologies of modern manufacturing.

Using the CIM laboratory as the lever, this thesis proposes a preliminary plan of
how to integrate the content of manufacturing engineering into the existing courses. This
integration will promote students' learning, reduce the learning complexity and at the
same time, provide students with the knowledge and skills necessary to compete in the
workplace. It will contribute a positive impact to manufacturing engineering in Ontario in
the 21st century.

5.2 Future Research

This thesis has sought to strengthen the position of manufacturing engineering
education in Ontario universities. The solution to achieve this aim is to develop the CIM
laboratory and integrate into it the Mechanical/Industrial Engineering courses with
Manufacturing Engineering. Although the research goals of this dissertation have been
explained, work in the area is far from complete.
Establishing an "effective" CIM laboratory alone does not ensure effective education in the field. Teaching methods and styles, along with learning styles need studying in order to assure optimum usage of the facility. This area was briefly addressed in section 4.5. Further research on various aspects of educational psychology would help the engineering educators to understand the student's needs.

More suggestions and ideas for the curriculum plan to integrate the manufacturing engineering education into the existing ME/IMSE courses should be gathered from the experts, faculty members, and practising engineers. A mail survey may help to collect the necessary data.
Appendix I

Courses listed for McMaster University and University of Calgary (3rd and 4th year only)

Course list of McMaster University Manufacturing Engineering Program (B.Eng.)

3rd year:

- Electronics and instrumentation
- Manufacturing laboratory
- Mechanical behaviour of materials
- Engineering mechanics
- Manufacturing engineering
- Modelling and numerical solutions
- Fluid mechanics
- Heat transfer
- Manufacturing processes
- Statistical analysis for engineering

4th year:

- Engineering and social responsibility
- Engineering: its history, philosophy and influence on civilization
- Engineering economics
- Real-time computer interfacing
- Computer aided manufacturing
- Project
- Industrial engineering
- Introduction to robotic mechanics
- Mechanical vibrations
- Control systems
- Computer aided design

Course list of the University of Calgary Manufacturing Engineering Program (ENMF)

3rd year:

- Computer-Aided Design and Graphics
- Mechanics of Materials
- Human Behaviour in Organizations
• Quality Assurance
• Integrated Manufacturing Systems I
• Manufacturing and Production Processes

4th year:

• Modelling and Simulation of Manufacturing Systems
• Computer Numerically Controlled Machines
• Robotics
• Organization and Technical Management in Manufacturing
• Manufacturing Engineering Design Methodology and Application
• Artificial Intelligence in Manufacturing
• Computer-Based Control for Manufacturing
• Special Topics in Manufacturing Engineering
• Manufacturing Practicum
• Production and Project Engineering
• Elements of Automation
• Product and Process Development

Appendix II

The descriptions of major Manufacturing Engineering related courses for McMaster University, the University of Calgary and the proposed program

McMaster University

Kinematics of Mechanisms
Introduction to the design of mechanisms. Analysis and synthesis of cams, gears and planar mechanisms. Force analysis of machine members.

Mechanical Engineering Design
Design of machine components. Review of stress analysis procedures; combined stresses; simple Design Factor approach; Variable loads and stresses with stress concentrations; bolted joints and springs; shaft and bearing design; brakes and brake systems.

Heat Transfer
Manufacturing Engineering
A general introduction encompassing the wide field of activities from iron and steel making through casting, rolling, forging, to cold forming, metal cutting, welding, bonding, electrical machining, surface treatment, mechanical handling, assembly, cleaning, packaging.

Computer Aided Manufacturing

University of Calgary

Fundamentals of Kinematics and Dynamics of Machines

Computer-Aided Design and Graphics

Integrated Manufacturing Systems

Modelling and Simulation of Manufacturing Systems

Manufacturing Engineering Design Methodology and Application
The preliminary and detailed design of a mechanical/manufacturing system with the emphasis on design for manufacturing, concurrent design, human factors, cost analysis, and material selection. Additional topics include design methodology and general design principles for manufactureability, design for forming, design for assembly, material removal, joining, assembly and assurance. Applications of formal design methods
including concurrent design, decision processes and probabilistic design to mechanical components and manufacturing systems. Also an emphasis is given to writing the design proposal, the final design report, and presentation to a committee from the department and industry

**Proposed Program**

**Kinematics and Dynamics of Machines**

**Machine Design**
Introduction to principles of mechanical design related to shafts, couplings, springs and gears. Analysis and design of mechanisms to meet functional requirements of positioning, force application and energy transmission. The laboratories consist of problems, case studies and the use of computer graphics and CAD packages for machine design problems.

**Heat Transfer**
Exact and numerical analysis of steady and transient conduction in solids. Solutions of one-dimensional and multidimensional systems. Principles of convection and solutions under laminar and turbulent flow over flat plates and inside and over pipes. Free convection. Thermal radiation between multiple black and grey surfaces. Application of thermal analysis methods with CIM laboratory.

**Simulation of Industrial Systems**
Introduction to simulation. Applications to queues, inventories and related models, simulation languages, input data analysis and model variation. Simulation output analysis, design of experiments. Use of computer software package.

**Computer-Aided Design and Manufacturing**
Fundamental concepts in computer-aided design and computer-aided manufacturing, numerical control of machine tools, computer-aided process planning, group technology, robotics and their applications, Flexible Manufacturing Systems. Hardware and software for CAD, Finite element method. NC, CNC, DNC. APT language, part programming. CAPP and MRP. Integration of CAD with CAM-justification; From CAD-CAM to FMS and CIM. Emphasis on the integration of manufacturing systems. Applications of these concepts using the CIM laboratory.
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VITA AUCTORIS

NAME Zhiqi Zhong
PLACE OF BIRTH Guangzhou, China
YEAR OF BIRTH 1968
EDUCATION South China University of Technology, Guangzhou, Guangdong, China
1986-1990 B. Sc.

University of Windsor, Windsor, Ontario, Canada