Manufacturing Education in the Global Manufacturing Scenario

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Abstract

This paper presents the current approach in manufacturing education at Texas A&M University (TAMU) in response to the alarming trend of manufacturing outsourcing in the USA. The revised curriculum reflects the need from industries where engineers with hard-skills are essential for technology innovation and soft-skills to effectively working with offshore manufacturers. In the lower-level courses, the basic manufacturing courses taught and illustrate different processes while emphasizing on the scientific foundation and introducing of emerging technologies. Laboratory exercises emphasize understanding, exploring, and integrating rather than following a rigid procedure. Frequent discussion of new technology innovation encourages students to explore new technologies in advanced courses. The senior and graduate courses give in depth knowledge and prepare students for research in emerging fields such as micro/nano manufacturing that help to shape the future products in biomedical, aerospace, and others. In addition to the discipline-specific hard-skills, the revised curriculum allows students to develop invaluable soft-skills when working as virtual teams on international industry-sponsored projects. The teaching program is also enriched and integrated with other NSF programs (Nanotechnology Undergraduate Education, Research Experiences for Undergraduates, and Research Experiences for Teachers) to reach out to other departments, universities, and high schools in the country.

Introduction

Taking advantage of lower cost and advance communications, companies in the US have been outsourcing their projects to other companies overseas. It was estimated that additional 10% of computer-related job moved overseas in 2004, 2 million financial service jobs will be moved by 2008, and a total of 3.3 millions high-tech service jobs will be out of the US by 2015[1]. Manufacturing industries in the US and developed countries have faced the same problem. Table 1 shows the shrinkage of manufacturing contribution to national gross domestic product (GDP) in the US from 19.4% in 1990 to about 15% in 2002. Similar trends were seen for other

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European countries (e.g., Germany and England), North American countries (e.g., Canada and Mexico), and developed Asian countries (e.g., Japan and South Korea). In 2002, the manufacturing contribution to GDP increased to 35.4% in China, 25.4% in Indonesia, 30.6% in Malaysia, and 27.6% in Singapore[2]. Shrinkage of manufacturing sector in the US has led to massive lay-off events starting around September 2000. A year later, the aftermath of the terrorism event in September 2001 worsened the situation as shown with higher and/or wider peaks in Figures 1 and 2. The number of manufacturing-related mass lay-off was as high as 652 events in July 2000 and affected 99,807 workers, but the startling lay-off events jumped nearly 100% to 1144 and 1125 in July and November 2001, respectively. At least 150,000 manufacturing workers were unemployed at the end of those months. Figure 3 shows the declining number of employed manufacturing workers from 17.3 millions in 1999 to 14.3 millions in 2004[3]. The average salary of manufacturing workers in the US, on the other hand, has been increasing steadily to about 10 times that of Asian workers. In an engineering survey, 48.1% of the companies had laid off engineers in one year period starting July 2003[4]. Foreign direct investment in US manufacturing also dropped from $43 billions in 2000 to $29 billions in 2003[5].

Table 1. Percentage of manufacturing contribution to GDP in North America, Europe, and Asia[2].

Countries	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**
Canada	..	..	..	19.5	18.6	18.3	18.3	18.7	17.4	16.2	15.7	16.0	17.2
Mexico	18.5	19.6	20.3	21.0	21.3	21.4	21.5	20.8	18.8	19.0	20.2	20.6	20.8
USA	..	15.2	16.7	17.2	17.6	18.0	18.3	18.9	18.9	18.5	18.6	19.0	19.4
Germany	22.8	23.0	23.0	22.9	23.4	23.2	23.1	23.5	24.1	24.6	26.8	28.5	..
UK	..	17.4	18.3	19.1	20.1	21.1	21.5	21.8	21.5	21.0	21.2	21.6	23.2
Cambodia	20.2	18.6	17.1	14.0	13.8	12.2	10.6	9.5	9.4	8.6	..	..	..
China	35.4	34.7	34.7	33.8	33.7	34.6	34.7	34.7	34.4	34.5	33.1	32.7	32.9
Hong Kong	4.5	5.2	5.8	5.7	6.0	6.4	7.3	8.3	9.1	11.1	13.5	15.3	17.5
India	15.6	15.3	15.9	15.1	15.8	16.7	17.7	18.1	16.9	16.1	16.2	16.1	17.1
Indonesia	25.4	25.0	24.9	26.0	25.0	26.8	25.6	24.1	23.3	22.3	22.0	21.4	20.7
Japan	..	20.5	21.8	21.8	21.9	22.8	22.9	23.0	23.0	24.1	25.6	26.5	26.6
S. Korea	23.7	24.4	26.1	25.1	24.8	23.5	23.9	24.9	..	..	..	..	..
Malaysia	30.6	30.5	32.7	30.9	28.8	28.4	27.8	26.4	26.6	25.9	25.8	25.6	24.2
Philippines	22.8	22.6	22.2	21.6	21.9	22.3	22.8	23.0	23.3	23.7	24.2	25.3	24.8
Singapore	27.6	25.7	28.7	25.2	24.7	24.5	23.9	25.0	..	..	..	..	..
Thailand	33.9	33.4	33.6	32.7	30.9	30.2	29.7	29.9	29.5	29.6	27.5	28.2	27.2
Viet Nam	20.6	19.8	18.6	17.7	17.1	16.5	15.2	15.0	14.9	15.2	15.4	13.1	12.3

Figures 1 and 2 also show the in-phase variation of manufacturing laid-off events as related to the total retrenchment events in the US. Since 1/3 to 1/2 of the total events are manufacturing-related, this indicates the importance of manufacturing sector to the US economy despite the increasing trend of offshore manufacturing outsourcing. The profit-driven US companies have moved manufacturing jobs to Asian countries where cheaper yet skillful labor and less stringent regulations are found. The remained manufacturing sectors in the US have to focus on either services (such as professional consultancy, and one-of-a kind prototypes) or high value added areas (such as R&D, micro/nano manufacturing for applications in biomedical, aerospace, defense, and homeland security).

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An outdated manufacturing education program cannot prepare students to work in new fields such as nanotechnology nor working in a dynamic outsourcing environment. Forward-looking universities have modified their education programs to effectively train students and provide their graduating engineers with necessary soft-skill and hard-skill to fit the global manufacturing scenario and to meet both short-term and long-term industrial needs. This paper presents the recent approach in manufacturing education at TAMU and compares it with other educational programs.

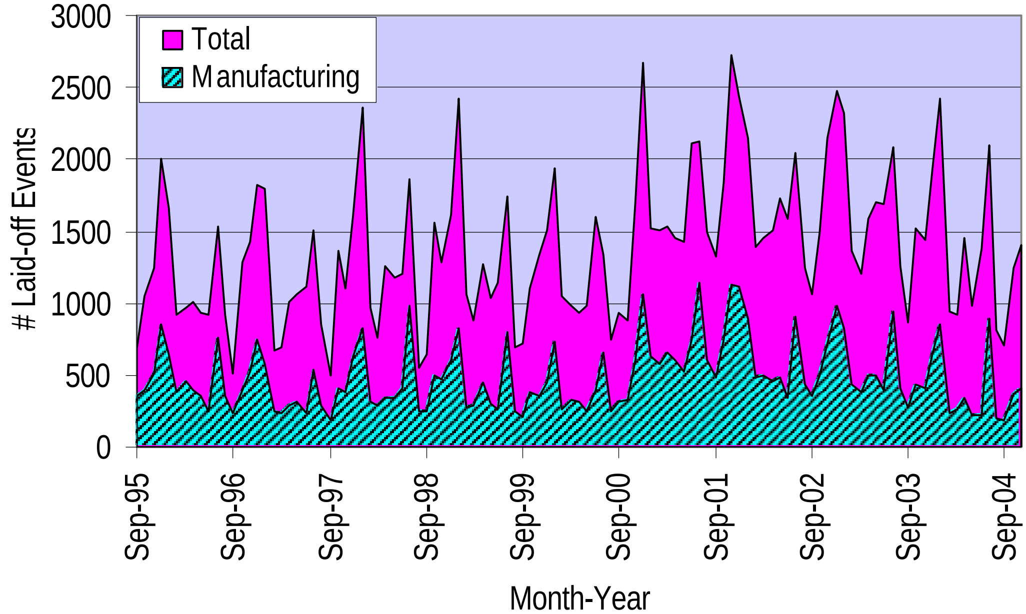

Figure 1. Manufacturing and total mass lay-off events (retrenchment announcements) in the US since 1995[3].

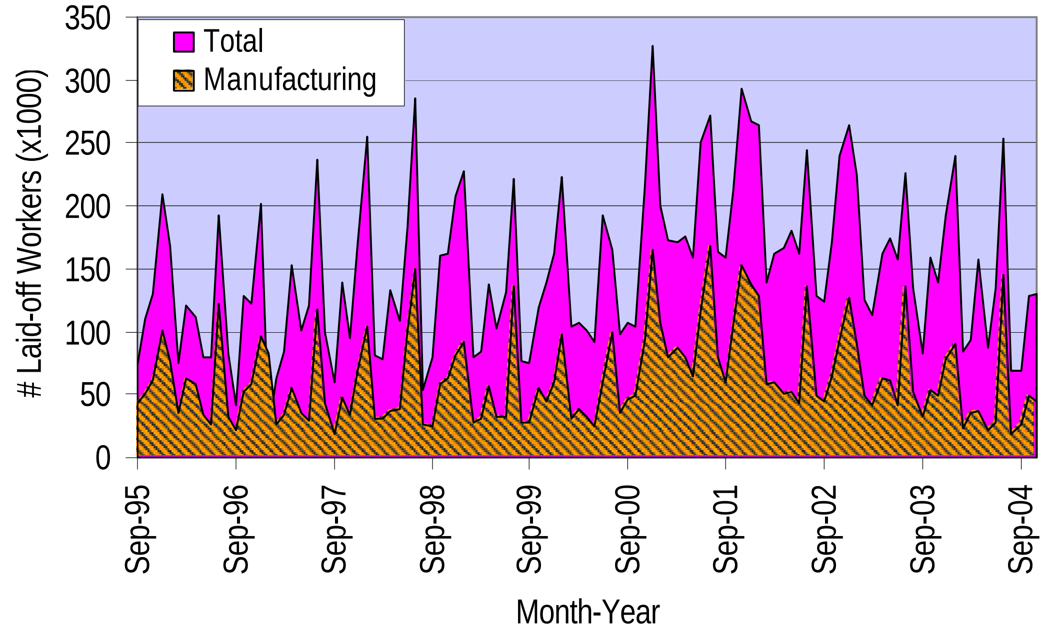

Figure 2. Manufacturing and total laid-off workers in the US since 1995[3].

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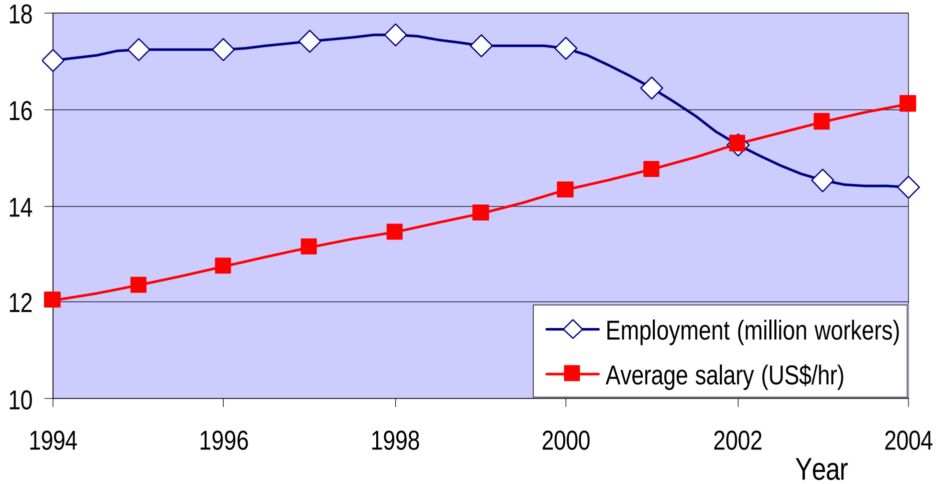

Figure 3. Number of employment and hourly salary of manufacturing workers in the US[3].

Manufacturing Education at TAMU

TAMU offers an undergraduate program in manufacturing & mechanical engineering technology. It is our ambition to establish a next-generation engineering technology program that builds on the best qualities of current engineering and technology programs, and enhances both curriculum and teaching philosophies to prepare students for the global manufacturing scenario. Steps have been made to move away from a passive mode of information transfer into a self discovery learning mode while providing stimulating hands-on laboratory exercises to the students. Joint appointments with other departments allow graduate students from mechanical engineering department and industrial engineering departments to research in the emerging fields such as global manufacturing and micro/nano manufacturing. Two parallel approaches have been implemented to provide both hard-skill (disciplinary specific skill) and soft-skill (non technical skill) to students.

Table 2. Previous Curriculum

Year	Courses for hard-skill training	Courses for soft-skill enhancement
1	CHEM 107: Chemistry ENDG 105: Graphics CPSC 206: C programming ENTC 181: Manufacturing process I ENTC 200: Introduction to manufacturing process MATH 151: Mathematics I MATH 152: Mathematics II	ENGL 104: Rhetoric ENGL 210: Technical writing GEEL xxx: General electives KINE 198: Fitness I KINE 199: Fitness II
2	ENTC 206: Nonmetallic materials ENTC 207: Metallic materials ENTC 275 Mechanics ENTC 281: Manufacturing process II PHYS 208: Electricity and optics PHYS 218: Mechanics STAT 211: Statistics	COMM 203: Public speaking INEN 302: Engineering economy GEEL xxx: General electives

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3	ENTC 303: Fluid mechanics ENTC 320: Quality assurance ENTC 361: Solids modeling ENTC 363: Design I ENTC 376: Strength of materials ENTC 380: CAD/CAM ENTC 383: Manufacturing systems IDIS 300: Industrial electricity ENTC 313: Welding (elective) ENTC 381: Electronics manufacturing (elective)	GEEL xxx: General electives
4	ENTC 370: Thermodynamics ENTC 402: Metrology ENTC 410: Automation and robotics ENTC 463: Design II	ENTC 412: Product and inventory plan ENTC 422: Project ENTC 429: Project/people management TEEL xxx: Technical elective GEEL xxx: General elective

Table 3. Revised Curriculum [The "* " indicates new change since 2003]

Year	Courses for hard-skill training	Courses for soft-skill enhancement
1	CHEM 107: Chemistry ENDG 105: Graphics CPSC 206: C programming *ENTC 181: Manufacturing process I *ENTC 200: Introduction to manufacturing process (Merge with ENTC 181) MATH 151: Mathematics I	ENGL 104: Rhetoric ENGL 210: Technical writing GEELxxx: General electives KINE 198: Fitness I KINE 199: Fitness II *ENGR 111: Foundation of engineering I
2	ENTC 206: Nonmetallic materials ENTC 207: Metallic materials ENTC 275 Mechanics *ENTC 281: Manufacturing process II PHYS 208: Electricity and optics *PHYS 218: Mechanics (Merge with ENTC 275) STAT 211: Statistics MATH 152: Mathematics II	COMM 203: Public speaking INEN 302: Engineering economy *ENGR 112: Foundation of engineering II GEEL xxx: General electives
3	ENTC 303: Fluid mechanics ENTC 361: Solids modeling ENTC 363: Design I ENTC 376: Strength of materials ENTC 380: CAD/CAM IDIS 300: Industrial electricity ENTC 313: Welding (elective) ENTC 381: Electronics manufacturing	GEEL xxx: General electives *ENTC 320: Quality management *ENTC 383: Manufacturing management and web-based resource planning
4	ENTC 370: Thermodynamics ENTC 402: Metrology ENTC 410: Automation and robotics *ENTC 463: Design II (Merge with ENTC 422) *ENTC 4xx: Micro/nano manufacturing (elective)	*ENTC 412: Global product and inventory planning *ENTC 422: Virtual team international project ENTC 429: Project/people management TEEL xxx: Technical elective GEEL xxx: General elective

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Tables 1 and 2 compare the curriculums before and after 2003. The main changes in the program include:

1) *Streamline technical courses*. There are slightly less number of technical courses due to merging of overlapping courses. The reduced numbers of hard-skill courses are made up with new soft-skill courses.
2) *Revise technical content*. The technical content of hard-skill courses are revised to prepare students for jobs that require globalization. Students are exposed to and competent in both SI and US-customary units, required to understand the scientific fundamentals rather than merely accepting the facts, equipped with problem solving skill rather than table-look-up or memorization skill. For examples, the ENTC 181 (Manufacturing Process I) covers not only traditional and nontraditional manufacturing processes, but also introduction of micromanufacturing processes that support nanotechnology. The ENTC 313 (Welding) is being revised to include microjoining technologies. The ENTC 380 (CAD/CAM) is to include examples of design and manufacture of microcomponents. The new course ENTC 4xx (Micro/nano Manufacturing) includes microelectronic manufacturing as well as other novel processes. The ENTC 410 (Manufacturing Automation and Robotics) addresses the automation using programmable logic controllers. Our automation laboratory and its award-winning web-based learning and tutoring system allow students to access and learn the topics independently.
3) *Enhance laboratory exercises*. Besides having hands-on experiences to complement the theory, students are encouraged to explore and integrate rather than following rigid step-by-step instructions. There are more teaching assistants in a laboratory for efficient utilization of the laboratory time and equipment. In all cases, the objective is to understand a manufacturing process capability and its limitation rather than to train students to master a specific technical skill.
4) *Expose to globalization*. Internet resources and information technology are used extensively for information dissemination and research. We are in the process to form virtual teams with senior students from different departments at TAMU and those from Singapore and Mexico to work on industry-sponsored problems. Students have to use available information technologies to communicate, transfer technical files, manage their own team, and to complete a one-year project under supervision of their respective professors. In the second phase of this program, the scope of such projects will expand from technical areas to include interdisciplinary and business components.
5) *Integrate with other university-wide programs*. Students taking the common engineering courses ENGR 111 and ENGR 112 will be exposed to different modules of the Nanotechnology Undergraduate Education (NSF-NUE) program that is designed to stimulate the students' interest in nanotechnology. Selected undergraduate students will join other national and international students in the Research Experiences for Undergraduates (NSF-REU) to promote research interest and going to graduate schools. Some other students will work with high school teachers during summer on another Research Experiences for Teachers (NSF-RET) program.

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This ambitious program at TAMU provides students with basic scientific foundation in traditional manufacturing as well as emerging manufacturing technologies. In addition, the program also provides students opportunities to work in a virtual global team and gain invaluable soft-skill through cross-cultural collaboration and enhancing courses. Graduating engineers will be capable to work and excel in international companies by utilizing their hard-skill to work on innovative technical projects, and use their soft-skill to integrate resources worldwide for efficient manufacture and introduction of their company products to the global market. Although the broader impact of our program is yet to be determined, we have received favorable support from industrial representatives and encouraging responses from our students.

Discussion

Convenient communication, globalization trend, and employment of graduates force educational institutions to constantly review their manufacturing programs to satisfy both short-term and long-term needs from industry. Current global internet system provides economical, efficient and reliable communication in real time across the boundaries between companies and countries. To further enhance the current internet capability, other information technology such as groupware was developed to facilitate communication, problem solving, trouble shooting, and decision making in global manufacturing environment[6]. The international standards in design /manufacturing and efficient shipping allow quality and consistent goods to be transported quickly around the world. These facts enable companies worldwide to outsource for high quality products and being cost competitive.

Industry needs qualified engineers to convert innovative concepts to marketable products, while educational institutions train future engineers for industry. There are close relationships among educational institutions, students, and industry where majority of trained engineers will join after graduation. With globalization, a company can bring work/project to a consortium of manufacturers, wherever the manufacturer might be, so that the project can be completed with assured quality and low cost. Similarly, a company now can post an advertisement for employment online and soon has to rank hundreds or thousands of resumes to shortlist few candidates from either domestic or overseas universities. Educational institutions, therefore, should be proactive to response to industrial needs to ensure a good fit between their graduating engineers and the global industry.

Students normally will consider future employment prospect before choosing their careers and schools. Because of the high rate of engineering lay off in the US, bright students might avoid a technical career and might choose non technical fields such as medical, law, or business. Forward looking educational institutions, therefore, should have attractive and quality programs to attract top students and almost guarantee employment to their graduates.

Bridging between energetic students and dynamically evolving industries, educational institutions must modify their curriculum to attract, retain bright students and train them so that the graduates can fulfill what industry needs now and to help propel industry into the next wave

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of technological innovation. In spite of the globalization trend, some educators responded negatively to the change in engineering curriculum and insist on keeping the traditional education since it provides engineers with specific skill and solid scientific foundation to advance science and technology. With the low employment opportunity in the US manufacturing sector, more and more foreign students are going back home after graduating from US universities and bring with them the technical knowledge. Increasing trend for graduated foreign students seeking employment at home, increasing trend of domestic students avoiding science and technology careers, and the alarming rate of manufacturing outsourcing have urged academicians to reposition their engineering curriculum, specifically the manufacturing educational programs.

To fit into the current manufacturing scenario, many educators have suggested to: (i) maintain the core scientific foundation to promote innovation and (ii) modify the current curriculum and teaching methodology to respond to the current outsourcing trend. Maintaining the basic scientific foundation to promote innovation is a necessary component in manufacturing education. The hard-skills that students learn from pure technical courses allows in depth understanding of the subjects and equips them with specific knowledge for innovation. Creation of innovative concepts leads to creation of new jobs and opportunities. For instance, in a recent meeting at NSF among industry, government agencies, and educators, representatives of various industries highlighted the acute shortage of qualified engineers in the field of micromanufacturing to design, manufacture, and integrate microsystems into highly demanded products[7]. Modifying the current curriculum, such as offering new courses in micro/nano technology, and teaching methodology in response to the current outsourcing trend is an important component of new manufacturing programs. In addition to the specific knowledge obtained directly from textbooks, students need to acquire other soft-skills such as entrepreneurship and cross-cultural communications skills to fit in the global scenario. A dynamic company would need capable engineers to work in a team, have a sense of marketing /entrepreneurship, and preferably have some international exposure[8]. Few approaches are suggested to provide the international component in education. A diverse team with a well mix of gender, race, ethnics, and cultural background help to promote cross-cultural communication, innovation, and creativity[9]. International student exchange program, that allows students to study abroad for one or two semesters, is another excellent avenue.

The revised manufacturing curriculum and pedagogical approach at TAMU are consistent with those from other universities. The "global virtual team" model in which engineers working together via internet is likely to be the life of professional engineers in near future. Several educational institutions are preparing their students for this scenario. At TAMU, students have access to an integrated virtual learning and intelligent tutoring system. This web-based virtual laboratory and tutoring system allows students and engineers to learn different aspects of programmable logic controllers at their own time and location, therefore, alleviating problems with setting up an expensive laboratory and sophisticated equipment[10]. Similar web-based virtual laboratories have been successfully established elsewhere[11,12]. We also are working on international collaborative programs that allow TAMU students to work with their virtual teammates in Mexico and Singapore though internet on industrial sponsored projects. At Carnegie Mellon University, teams of students with multidisciplinary skill are working on

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internet collaborative projects with another university in the Netherlands[9]. Students at Nanyang Technological University in Singapore are encouraged to study additional foreign languages as elective courses in addition to a summer program on technopreneurship. At the University of Michigan, students of different background are exposed to both technical and business aspects. The assignment is to create a start up company to provide a new product that fits to the global market. The teams have to come up with a business plan, manufacturing plan, and description of the product and its detailed design[13]. At the University of Calgary in Canada, students work on a full-year project to address not only technical issues but also trained on problem solving, communication and project management skill[14]. Syracuse University recently modified its manufacturing curriculum to address the discipline-specific courses while providing multidisciplinary skill to students. A new manufacturing program with optional information management or engineering management components is available for students. Another E-manufacturing course explores and addresses issues with integration of manufacturing equipment, data collection/communication/control, and global resources[15].

Summary and Conclusion

The industrial globalization trend is increasing due to rapid advances in information technology, less trade restrictions, and efficient transportation worldwide. Manufacturing outsourcing in the US is inevitable to keep products competitive. This outsourcing trend has significantly impacted the American manufacturing labor force and taken away millions of jobs in the last few years. As the result of massive manufacturing lay-offs and refocusing of the remaining US companies, engineering educators have been reevaluating the curriculum and pedagogical approach to help the industry and to attract/retain students in technical fields such as manufacturing. In general, it has been agreed that future manufacturing engineers must not only have the hard-skills to solve complex technical problems and invent novel technologies, but also possess the soft-skills to work harmoniously in a team crossing boundaries among companies and countries. The manufacturing program at TAMU has being revised to (i) streamline the technical courses and include micro/nano manufacturing, (ii) promote understanding of the scientific foundation and embark problem-solving skill to students while providing simulated working environment in global manufacturing.

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