# AC 2012-3749: REVITALIZING U.S. MANUFACTURING TO CAPITALIZE ON INNOVATION

**Dr. Brian W. Anthony, Massachusetts Institute of Technology**

Brian Anthony is the Director of the Master's of Engineering in Manufacturing Program and Co-director of the Medical Electronic Device Realization Center at MIT. He has more than 20 years of product realization experience, including instrumentation and measurement solutions for manufacturing systems and medical diagnostics and imaging systems.

**Dr. David E. Hardt, Massachusetts Institute of Technology**

Professor Hardt is a graduate of Lafayette College (B.S.M.E., 1972) and MIT (S.M., Ph.D, 1978). He has been a member of the mechanical engineering faculty at MIT since 1979. His disciplinary focus is system dynamics and control as applied to manufacturing. His teaching focuses on control, dynamics and manufacturing processes. His research has been on flexible automation, and process control, with an historical emphasis on welding and forming processes, and a current focus on micro and nano scale polymer device fabrication and micro-contact printing. This new work focuses on product such as microfluidic devices and large-scale surface patterning for flexible electronics and photovoltaic substrates. Hardt has taught classes in both mechanical engineering and manufacturing, and has led the creation of a new graduate degree: master's of engineering in manufacturing at MIT. This is the first professional degree offered by the ME Department at MIT and is the culmination of many years of course and curriculum development.

Prof. Hardt served as Director of the MIT Laboratory for Manufacturing from 1985 - 1992 and as Engineering Co-Director for the MIT Leaders for Manufacturing Program from 1993 to 1998. Since 1999 he has bee the co Chair of the Singapore MIT Alliance (SMA) Program: "Manufacturing Systems and Technology", a research and teaching collaboration with Nanyang Technological University in Singapore.

Prof. Hardt also serves as the Graduate Officer of the Department of Mechanical Engineering at MIT.

# Revitalizing US Manufacturing to Capitalize on Innovation – Through Education


## Abstract

We find that a conventional engineering degree approach to education is not sufficient to meet the new challenges in the ecosystem of manufacturing, design and business innovation, and product realization. Instead a new form of engineering education, the "Professional Masters" is required that takes the grounding provided by typical Bachelor of Science in engineering degree and provides condensed, formalized, experience with systems, applications, projects, and non-technical topics to create a true professional ready to maximize their value to the company and ready to use their experience to lead.

The Master of Engineering in Manufacturing (MEngM) at MIT was developed over a period of 10 years, and has more than 200 alumni. It is based on the notion of a need for graduate level education in the profession of engineering that is not fulfilled by the conventional research-oriented Master of Science degree. We have learned that there is a large pool of outstanding students who will seek out this degree once it is offered, and who have as alumni drawn strongly positive reviews from their employers.

Students in the program, a cross-section of the best and the brightest, are drawn to the notion that manufacturing is how technological advances and innovations become rooted in a nation's economy. They want to understand the essential components and growth opportunities of the foundation - manufacturing and innovation - of an economy.

There are many indicators of the decline of manufacturing in the US, most of them economic. One troubling indicator is the persistent lack of interest in careers in this field, particularly at the collegiate and post-graduate level. While there are continual calls for better labor force training and government programs to support the same, there are actually disincentives for promising young professionals to enter this field. Societal perception and industry needs seem to run counter to one another. We propose that the MEngM can serve as one example of a new national model for professional manufacturing engineering education. It can profoundly impact the US's innovation ecosystem which is the foundation of our manufacturing based economy today and in the future.


## Introduction

Ecosystem of Manufacturing and Innovation

The US's historic technological and operational advantage is due, in large measure, to the skills and innovation of highly educated and highly trained engineers, and a technologically-advanced workforce. This is our most valuable resource. However, the industrial base upon which the economic engine of the US runs has dramatically changed over the past decades. For years the US has watched as its manufacturing industries and corresponding jobs have migrated to other countries. Consequently, its ability to compete globally in manufacturing has substantially weakened, concurrently threatening the country's technology innovation capability.

Manufacturing is how technological advances and innovations are rooted in a nation's economy. No single "next generation manufacturing technology" will solve the country's

economic problems, but perhaps a revitalization of the entire enterprise and ecosystem, in addition to a rethinking of how manufacturing is integral to innovation, may.

Societal Perception and Industry Need

The American public has seemed to resign itself to the fact that the US is on the verge of losing its decades old supremacy in manufacturing (1). However, the US must strengthen its ability to manufacture, as there is ample evidence to support that it's the basis for economic growth and employment (2). In the US, the popular perception of the value and importance of manufacturing has waned. "Rewarding, stimulating, and upwardly mobile careers are available in manufacturing. Surprisingly companies indicate that they struggle finding the talent to fill positions. Perhaps this is because we fail to convey the excitement and opportunities in manufacturing," said Hans-Peter Schaefer (3).

A recent report by the President's Council of Advisors on Science and Technology (PCAST) found that the country's 2001 surplus trade balance in advanced manufactured products slid to an $81 billion deficit by 2010. Furthermore, the US has already relinquished its leadership in high-tech industries, which typically employ highly-skilled workers (4). Following the recommendation made by PCAST, President Barack Obama created the new Advanced Manufacturing Partnership (AMP) (5), which collectively combines the efforts of industry, government, and academia to identify and invest in the country's manufacturing innovation.

One focus of AMP is to look at university programs that focus on Advanced Manufacturing (6). This effort does not explicitly consider, for example, research labs or centers with some manufacturing related work, as these are best considered under the heading of specific advanced manufacturing technologies. Instead this effort is aimed at programs and degrees that give the student a comprehensive view of manufacturing. What distinguishes a comprehensive program is that it provides both a technological and an operational perspective to the student (7). The latter is the component that is most often missing from graduate level research programs in engineering. By the same token programs that focus only on operations alone without the other topics cannot be considered "comprehensive".

The evidence for the need for such programs is still mostly anecdotal, but at a recent "Manufacturing Summit" (3), a number of manufacturing executives of multinational companies decried the lack of candidates to fill entry and leadership positions in their factories. It is also common to hear that it takes many years to take a typical graduate and train them sufficiently to lead a manufacturing operation. Since there is a lack of named programs at most schools, indicators such as salaries and career trajectories are difficult to track at this time.

University Programs

A survey of the 6 universities (Massachusetts Institute of Technology, Carnegie Mellon University, Georgia Institute of Technology, Stanford University, University of California-Berkeley, and University of Michigan) participating in the AMP initiative has shown the following:

None have a named undergraduate degree in Manufacturing, while several have at least one comprehensive program at the graduate level. These range from certificate programs to enhance

the background of "regular" research students (e.g. Georgia Tech) to specialized professional degrees specifically aimed at manufacturing with a blend of technology and operations (e.g. Michigan's and MIT's Master of Engineering degrees) or technology and management (e.g., Berkeley's Master of Engineering program) Also, operations as a topic is often the subject of management education, several of the AMP schools have manufacturing related programs as part of their business schools, and two (again Michigan and MIT) have programs that combine engineering and business degrees with a focus on manufacturing.

All of the AMP schools have conventional SM and PhD research in manufacturing related areas and some, such as Carnegie Mellon and Michigan, offer a Master of Science degree specialization in manufacturing, with specific course requirements. However these curricula focus almost exclusively on technology related subjects.

A key characteristic of comprehensive manufacturing programs is an intimate connection with industry, and most importantly with the manufacturing organization as opposed to the R&D or advanced technology groups. This part of industry is responsible for the successful production of goods and is the source of both challenging problems and challenging careers for the students. It also is the part of industry that research university faculty seldom, if ever, interact with. All three of the Master of Engineering programs (Michigan, Berkeley and MIT) report strong interaction with industry including seminars, projects and even limited program funding.

Trends and Concerns

Several of the AMP schools have either dropped programs in manufacturing or report that student interest (particularly US students) has waned. Reasons for this are numerous, including the image problem in the US, but also comprise more subtle problems. For example, the Master of Engineering programs, which tend to fit the "comprehensive" model best, do not lend themselves to conventional graduate education funding models, and can prove too expensive for even the most dedicated students. This problem is particularly severe for US students who know they can opt for a more narrow research program and be funded as research or teaching assistants.

Another impediment to longevity is the importance of continuous participation of the manufacturing industries. The role of industry is crucial to the success of these programs, but sustained engagement from industry is difficult, and can wax and wane depending on their particular corporate strategy and health. Even the most dedicated participants find themselves having to leave programs when times get tough or when corporate priorities shift (8). As a result, maintenance of these relationships typically requires a permanent non-faculty staff, which adds to the expense of such programs, and the continually shifting industry landscape, while helping to keep programs current, also leads to a continual uncertainty about the program viability.

Likewise, it is evident that universities themselves have not learned where manufacturing best fits in academia. It does not fit well into typical boundaries of departments or even schools, and as a result often finds itself marginalized. By contrast there has been a longstanding trend of eliminating specific Manufacturing Engineering departments in the research universities and a slow reduction or elimination of manufacturing from most industrial engineering programs over the past few decades.

If one starts with the premise that US manufacturing excellence includes the need for graduates from such comprehensive degree programs, it must be concluded that nationally we are not addressing these needs. What emerges is a picture of local programs that rise and fall with local enthusiasm and industry interest, and which are on the whole isolated, and independent. US Government support for graduate programs specifically excludes Master of Engineering programs as they do not have a research product at their core, and reliance on industry financial support has proven to be very difficult to sustain.

**Professional Engineering Education, The Master of Engineering in Manufacturing at MIT**

At MIT, we believe that a conventional engineering degree approach is not sufficient to meet the new challenges in manufacturing, design and business innovation, and product realization. Instead a new form of engineering education, the "Professional Masters" is required that takes the grounding provided by typical Bachelor of Science in engineering degree and provides a capstone of systems, applications, projects, and non-technical topics to create a true professional ready to maximize their value to the company and ready to use their experience to lead.

The Master of Engineering in Manufacturing (MEngM) is a twelve-month professional graduate-degree program in Mechanical Engineering that is intended to prepare the graduate to assume a role of technical leadership in the manufacturing and product realization industries. The MEngM combines formal coursework with hands-on industry-based experience. The degree is aimed at practitioners who will use this knowledge to become leaders in existing as well as emerging manufacturing companies. The degree program includes four course-based components - Manufacturing Physics; Manufacturing Systems; Product Design, Innovation, and Realization; and Business Fundamentals - and an overlapping 8 month group project in a manufacturing company. Our goal is to create technical engineering leaders who possess a strong systems view.

Students are exposed to the full range of topics necessary for manufacturing excellence, and can experience many of them with class-based projects and seminars, and finally, a group – based project in industry on a topic that the company feels is vital to their continued success. The MEngM provides "compressed and formalized experience" with a scholarly backdrop that makes the process of rapid future learning a natural and familiar task. The admitted student has, on average, one year of work experience in the manufacturing industries, and is in the range of zero to five years post undergraduate.

The professional engineering education of the MEngM connects academia (teaching and research) and industry (continuing education, operations, and research). The industry collaborations and company-based group projects address the needs of industry, advance the state and quality of education of our graduates, and strengthen manufacturing and innovation in the US.

- It emphasizes advanced engineering practice versus the more conventional research oriented Master of Science degree.
- It can be completed in 12 months.
- The curriculum emphasizes both theory and group project work, both in the classroom and in the field.
- It covers both technology and systems of technology

- Industry projects are an integral part of this degree, which should fit well with the needs of industry.
- It represents an opportunity for educational innovation that we believe will be of great benefit.

Curriculum

The MEngM is designed to give students a broad and solid understanding of the core principles of manufacturing. Students take a comprehensive curriculum of Process and Assembly Physics (Materials, Machine, Automation, Quality), Factory and Supply Chain Systems (Material flow in factories and supply chains), Product Design (Need driven product development and design for manufacture), and Business Management and Operational Excellence (Fundamentals of starting a company, global trends and industry seminars) subjects. The capstone activity is a Group Project leading to a Project Thesis.

The curriculum comprises four course-based components: manufacturing physics, manufacturing systems, product design, and business fundamentals. Each involves both individual and team work on class projects. From the January until the end of the second semester the group project is pursued on a part-time basis and then full time during the summer, for a total of eight months of involvement with the project company.

Fall Semester
Manufacturing Processes
Introduction to Manufacturing Systems
Design and Manufacturing for Assembly
Management in Engineering

January
Initiate Industry Group Project
Entrepreneurship seminars series
Tours of New England Industry

Spring Semester
Industry Group Project (part time work as a group)
Manufacturing Process Control
Product Design
Supply Chains and Logistics
Professional Seminar

Summer Term
Full time work on site for project
Completion of Project Thesis

Industry Project

The group projects have proven to be one of the most important facets of the MEngM. They emphasize solving problems of real value to the host company, and also emphasize working as a

group. These two elements have allowed many of the projects to yield great value for the company and provide unique and highly valued experience for the student. These projects, the capstone activity, done in groups of three students per site, form the basis for the thesis project portion of the degree. This project typically involves solving near-term problems for the company, as well as working at their site under the supervision of an MIT faculty member.

Given the short duration of the degree program, it can be a challenge to give the student group sufficient time to understand the company problems, let alone work to solve it. This dilemma is overcome by starting the projects between the two semesters of the degree and then working on them part time during the spring. When the full time work in the summer begins, the group is already well known by the company supervisors and is well along the way to the problem solution.

A number of companies propose the projects, and in late Fall a matching process teams the students with their project and faculty advisors. The projects vary by industry, but the initial work at each company site takes place during January, followed by once-weekly meetings during the Spring semester. From late May to mid August, the groups then work full time on-site to complete their projects. Each student then documents their contribution with a project thesis, which is submitted to the MIT thesis advisor for approval. Most projects involve a stipend paid to the student by the company.

Recent projects include:

- Implementation of RFID for Parts Tracking in a Equipment Manufacturing Factory
- Robust Product – Process Design for a Diagnostic Microfluidic Device
- Process Improvement in a High Volume Packaging Material Manufacturing Plant
- Process Improvement for Manufacturing of High Lift Oil Well Pumps
- Process Improvement for Manufacture of Deep Well Instrumentation Systems
- Development of a Logistics Resource Allocation System
- Supply Chain Planning of Global Electronics Manufacturer for Short Life Cycle Products
- Analysis, Scheduling and Planning in Wafer Fabrication Systems
- Analysis, Appraisal and Improvement on Airbag Sensor Assembly Line
- Improvement Study on Internal Supply Chain in Offshore Industry
- Optimization of Cleaning Process for Castings

Key to Success – Admissions, Cohort, and Projects

Several factors are key to the success of the program. First of all the admission process is as rigorous as ever with respect to technical competence. The program is in the department of mechanical engineering, but students with civil, electrical, ocean, chemical, and etc. backgrounds are admitted as long as they have a sufficient overlap with a core of undergraduate mechanical engineering. Beyond technical competence, a candidate's desire to be a leader, an innovator and to work in an industrial setting is evaluated. Two focused essay - one on manufacturing and one on leadership are required; all short listed applicants receive a personal interview. Put simply, we look for candidates that are highly motivated to see things get built, understand why they want to do the program, and have a vision for their career after the degree. The majority of the admitted

students has prior work experience in the form of internships, a year or two of work experience after their undergraduate degree, or grew up working in their family's manufacturing business.

Second, we have a unified curriculum that emphasizes state of the art principles and methods, and combines that with project and case study material. This may seem a bit constrained, but it develops a very strong learning cohort among the students, and makes sure that they all have the comprehensive knowledge their future employer's value. In addition to the technical courses, students take an accelerated writing and communications seminar; this includes writing conferences, personal attention, feedback on technical presentation style and content, and commented thesis drafts.

Finally, we have a significant capstone activity called a "Group Project in Industry". It spans nearly 8 of the 12 months of the degree (both part time and full-time), and involves significant, valued-added problem solving in local companies under the supervision of a faculty member. Companies have found that our students can be challenged and provide real value for their time there, and students have come to see this as perhaps the most valuable part of the program (9). Project definitions, and company partnerships, require a significant time commitment from the program director; the projects are defined so that they address a real (immediate, value added) need of the company, are aligned with the pedagogical goals of the program, and matched to students' interests.

**Career Opportunities and Impact**

The Master of Engineering in Manufacturing prepares the graduate for leadership positions in manufacturing and related industries. Through the carefully coordinated curriculum, project orientation and a capstone group project in industry, the student develops a facility that fosters a wide range of careers - from new process technology and technology improvement to product development, manufacturing systems, and manufacturing logistics.

Graduates have already moved into a variety of careers in manufacturing that range from semiconductor process engineering, new product introduction, and factory management to supply chain design and implementation. Some graduates have ventured out on their own to provide consulting services, and some go on to earn doctorates and become management and engineering faculty.

Early on, our industrial partners have identified our graduates as "different" (9). This difference is identified as outstanding team players, quick learners, and determined problem solvers. Specific examples of what recent graduates have achieved:

- Developing disruptive manufacturing technologies for the emerging field of soft-lithography
- Optimizing space utilization and supporting continuous improvement activities for an international logistics corporation
- Applying operations management techniques to the production of offshore oil rig platforms to problems of inventory management plant layout and workload balancing
- Designing consumer electronic products, from concept to production to market
- Coordinating a multi-billion dollar factory conversion in the semiconductor industry, and introducing rigorous planning methods for this purpose

- Serving as a sales manager for an aluminum company with customers in the auto and consumer electronics industries
- Working in teams with managers and engineers to develop a new distribution structure for a major home furnishing manufacturer.
- Working on bringing a new all-electric vehicle to volume production.

**Future**

Universities must establish stronger relationships with the operations aspect of US manufacturers. This has the corollary of the development of more professional master of engineering degree programs, which depend on such relationships and the full acceptance of such degrees by academia (10).

The major research universities have a special responsibility to lead on this, and to establish what "Advanced Manufacturing" should mean and why it is so vitally important. They must acknowledge that the conventional post-war research model may not be the best for addressing the needs of American manufacturing. With the proper incentives, these schools could collaborate to establish a new educational model that could propagate nationally into all tiers of schools.

Universities, Industry and the Federal Government need to make programs in manufacturing at least as attractive as other graduate programs for the interested student. Targeted national programs, attractive funding opportunities, and even agencies that highlight the national importance of these studies can have a profound effect on student career decisions. Partnerships among Universities, Industry and Government have existed in the research arena, but not in advanced manufacturing educational programs. With the unique requirements of these programs, such a partnership may be the necessary ingredient in achieving the needed impact.

<u>Federal Support of Manufacturing Education</u>

We work to initiate a federally funded fellowship or traineeship program to give both financial support and social notoriety to graduate education in Manufacturing and Manufacturing Innovation. We believe that federal recognition - marketing and financial - can contribute significantly to revitalizing and invigorating US manufacturing.

Professional programs in manufacturing labor under two major disadvantages. The first is cost; a professional degree with a significant industry project is not aligned with Research or Teaching Assistant funding mechanisms. The second is the non-positive public-opinion regarding US manufacturing; this hides the phenomenal opportunities, and need, for the best and brightest.

A group of similar programs at several well known schools can make a significant impact. Our programs provide professional education in manufacturing and create greater interest and excitement in careers in the field. Given the emphasis of the Obama administration on strengthening the US Manufacturing base, now seems like the time to push to initiate federally funded support.

## Bibliography

1. **Manufacturing Institute.** 2011 Public Perception Report. 2011. http://www.themanufacturinginstitute.org/Research/Public-Perception-of-Manufacturing/2011-Public-Perception-Report/2011-Public-Perception-Report.aspx.
2. —. 2011 Skills Gap Report. http://www.themanufacturinginstitute.org/Research/Skills-Gap-in-Manufacturing/2011-Skills-Gap-Report/2011-Skills-Gap-Report.aspx.
3. **Laboratory for Manufacturing and Productivity at MIT.** Revitalizing US Manufacturing to Capitalize on Innovation. *6th Annual Manufacturing Summit at MIT, An LMP Symposium.* October 2011. http://web.mit.edu/lmpsummit/index.html.
4. **PCAST.** Report to the President on Ensuring American Leadership in Advanced Manufacturing. June 2011. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-advanced-manufacturing-june2011.pdf.
5. President Obama Launches Advanced Manufacturing Partnership. 2011. http://www.whitehouse.gov/the-press-office/2011/06/24/president-obama-launches-advanced-manufacturing-partnership.
6. Advanced Manufacturing Office: Advanced Manufacturing Partnership. 2011. http://www1.eere.energy.gov/industry/amp/index.html.
7. **Society of Manufacturing Engineers.** Curricula 2015, A Four Year Strategic Plan for Manufacturing Education. 2011.
8. Industry Perspective, Managing Interns. 2009. http://www.computer.org/cms/Computer.org/ComputingNow/homepage/2009/1209/W_CO_ManagingInterns.pdf.
9. **MIT News Office.** They're mastering manufacturing. *A distinctive MIT program trains engineers and managers who want to build careers on the leading edge of industrial production.* March 1, 2012. http://web.mit.edu/newsoffice/2012/manufacturing-masters-program-0301.html.
10. **National Academy of Engineering.** *The Engineer of 2020: Visions of Engineering in the New Century.* s.l. : The National Academies Press, 2004.