RE-SHAPING U.S. MANUFACTURING FOR GLOBAL COMPETITIVENESS

A workshop report submitted to the

National Science Foundation

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Executive Summary

A National Science Foundation-sponsored workshop on "Innovations and Operations of Manufacturing Systems" was held May 12 – 14, 2010, at the University of Michigan, Ann Arbor, in conjunction with a one-day National Symposium and Regional Meeting of the National Academy of Engineering, entitled "Engineering to Improve the Operations of Manufacturing Enterprises". The initial goal of the workshop was to develop a set of recommendations on new areas of research and education in manufacturing systems innovation and operations, but discussion made it clear that high-level manufacturing infrastructure support, including coordinated federal policies and support for research and development, is essential to revitalize U.S. manufacturing. The fourteen workshop recommendations are summarized below:

Strengthen the Failing Manufacturing Infrastructure in the U.S. and the Government's Role in Supporting Manufacturing Research and Innovation

Recommendations:

1. Establish a blue ribbon panel to examine manufacturing and develop the government policies needed to support a more effective manufacturing infrastructure.

2. Establish a network or cluster of regional Manufacturing Innovation Centers, following the model of the Discovery-Innovation Institute (DII).

3. Enhance coordination of government agencies in funding manufacturing research and innovation.

4. Create a component of the STTR and SBIR industry partner research program to solely support the application and commercialization of university research by small businesses.

5. Support small and medium-sized businesses with manufacturing modeling and simulation systems and software capabilities.

Develop Manufacturing Education Programs for K to Gray

Recommendations:

6. Redefine the image and vernacular of manufacturing.

7. Develop a coherent manufacturing education curriculum.

8. Support collaboration in manufacturing engineering education across universities.

Support Research in Open Architecture Products, Enabling Open Innovation, Collaboration and Value Creation

Recommendation:

9. Provide support for research in technologies that enable implementation of open architecture products to spur innovations and value-creation by small-businesses.

Make Sustainability a Business Imperative in All Phases of Product Life Cycle

Recommendation:

10. Support re-manufacturing, including research in recovery methodologies, business models, logistics, and design for remanufacturing.

11. Develop and support implementation of engineering tools, standards and assessments and certification systems for the life cycle impacts of products and services.

Enhance Manufacturing Systems Research

Recommendation:

12. Support further development and integration of models and databases used to simulate manufacturing system technologies, process operating conditions, and workforce capabilities to enable faster responses to the uncertainties in supply chains, workforces and market demands.

13. Support the development of improved logistical models and simulation methods to consider the combined costs of transporting raw material, parts and finished products, regional energy sources, and regional workforce skills and capabilities.

14. Support development of systematic methodologies in manufacturing scale-up.

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Workshop Participants

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Jian Cao	Northwestern University
Donald Chaffin	University of Michigan (co-chair)
Josephine Cheng	IBM
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Paul Nuyen	The Boeing Company
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John Sutherland	Purdue University
Bin Wei	General Electric Global R&D
Donald Winter	University of Michigan and former U.S. Secretary of the Navy

Other University of Michigan Faculty Participants

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Introduction

Manufacturing is essential to the economic well-being of a nation and the quality of life of its citizens. "To live well, a nation must produce well [1]." The United States, for over a century, has been the global leader of manufacturing, creating tremendous wealth for the nation. However, the manufacturing sector is now faced with enormous challenges. The manufacturing share of the U.S. GDP has declined from the 33% in the 1950s to 13.4% in 2007 [2]. From 1998 to 2009, the manufacturing sector lost approximately 6 million jobs, from the employment high of 17.6 million 1998 to 11.7 million at the end of 2009 (Bureau of Labor Statistics, 2010 [3]). This drastic job loss was mostly attributed to globalization and outsourcing, even though steady and continuous productivity improvement (at a 3.4% annual rate from 1987 to 2008[4]) also contributed to a portion of the loss. The challenge was recently summarized by Ray Lane at an NAE Forum entitled: "Rebuilding a Real Economy" when he stated: "Americans can still manufacture products at lower costs than the global competition. But to do so they will need to take advantage of new production systems that greatly improve efficiency" [5].

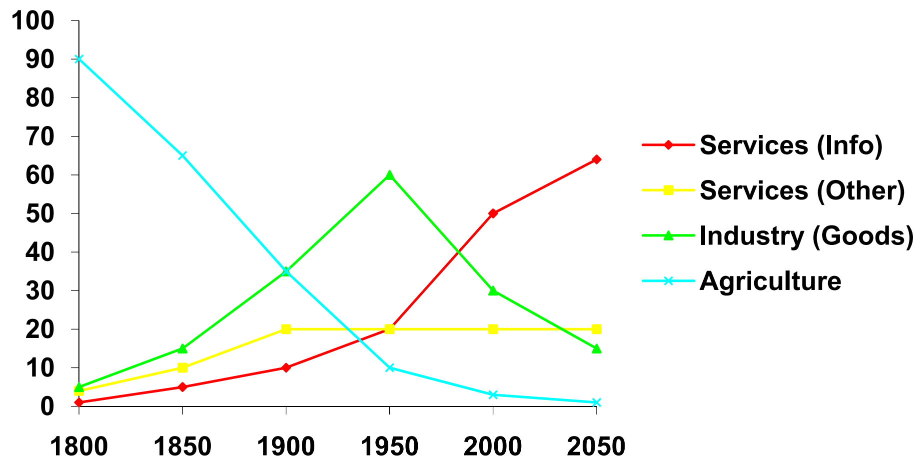


Figure 1: U.S. % Employment by Sector, *History and Projection*. Source: Stuart Feldman, IBM Research, Presentation at Carnegie-Mellon University, 29 June, 2005.

This dramatic job loss is disturbing as it has made manufacturing an unattractive career choice for young people entering engineering and technical schools. The shortage of students interested in manufacturing raises serious questions about our ability to provide the technologies and methods needed to improve the efficiency of manufacturing enterprises and provide for our national security and defense needs.

The United States has enormous opportunities to revitalize manufacturing. The grand challenges of energy and sustainability present us with many opportunities to develop innovative, green products and design the new manufacturing systems needed to create these products. Remanufacturing of older products to meet new consumer demands can provide both energy savings and additional jobs. This is particularly important to our military, along with retrofitting and upgrading systems to meet changing defense needs. In addition, market globalization and diverging consumer interests demand that manufacturers develop products that are tailored to individual regions, cultures and the personalized needs and preferences of consumers. In summary, our challenge is to use these innovations in products and manufacturing systems to create new employment opportunities and revitalize the U.S. manufacturing industry.

To address these challenges and take advantage of the opportunities, a National Science Foundation sponsored workshop on "Innovations and Operations of Manufacturing Systems" was held at the University of Michigan, Ann Arbor, May 12-14, 2010, in conjunction with a one-day National Symposium and Regional Meeting of the National Academy of Engineering, entitled "Engineering to Improve the Operations of Manufacturing Enterprises". The workshop brought together 22 leaders from academia, industry and governments to develop recommendations to revitalize U.S. manufacturing. The NAE Symposium featured keynote speakers and panels on topics of product development and manufacturing systems (See NAE Symposium Summary, Appendix I] and had an attendance of about 160 people, including 27 graduate students and faculty members from 23 different universities.

The Workshop Process

The goal of the workshop was to develop a set of recommendations on new areas of research and education in manufacturing systems innovation and operations. These recommendations have the potential to improve the U.S. manufacturing capabilities, to increase our ability to meet changing markets and environmental requirements, to meet our national security and defense needs, and to create sustainable domestic jobs. The participants addressed the following questions and received a written compilation of responses prior to the NSF workshop:

1. What new products can you suggest that will create and/or sustain manufacturing jobs in the U.S.?
2. What type of cost effective technologies and manufacturing systems should be developed to support these products?
3. How can we adapt to market demand and shorten lead times in our current manufacturing systems? How can this process be improved?
4. What role will small and "green" businesses play in the development of these new products?
5. What role could or should the government play in assisting small and green business in the manufacturing sector?

6. What suggestions do you have for creating a more qualified and diverse workforce to create sustainable manufacturing in the U.S.?
7. How should we address product design for regional markets considering culture, region, and regulations?
8. What advanced role could robotics play in supporting people and flexible automation?
9. To what extent should flexible manufacturing include physics, psychology and mathematical considerations?

During the NSF Workshop on May 12, each workshop participant briefly presented his/her views on the above questions and the opportunities in product and manufacturing innovations that s/he considered most important. Each of these presentations was followed with extensive discussions. Three break-out sessions followed: 1) Product Innovations, 2) Manufacturing Systems Innovations, and 3) Education and Workforce Development. Each break-out group presented their initial impressions and recommendations to the workshop group as a whole in the afternoon of May 12, and again at the NAE Symposium on May 13. This latter set of presentations allowed the 160 symposium attendees to ask questions and provide additional insight regarding these issues of concern.

Workshop participants spent the morning of May 14 reviewing and digesting the presentations and discussions, including those from the May 13 NAE Symposium. These discussions, reviews and syntheses led to higher-level questions on manufacturing infrastructure, including policies and coordinated federal support for manufacturing R&D, in addition to specific research questions on manufacturing systems. The following recommendations are the outcome of these final discussions. It should be noted that many of the recommendations are similar to the recommendations from a November 1991, NSF-sponsored workshop [6]. Unfortunately, the earlier workshop recommendations have been largely ignored resulting in a greater sense of urgency nine years later. The May 2010 workshop participants note that we are currently at a tipping point where additional inaction on these recommendations may lead to irreversible consequences for our manufacturing and innovation capability, our future economy and even our national security. It is the view of the workshop attendees that the current recommendations need immediate attention from the highest level of government.

Recommendations

Strengthen the Failing Manufacturing Infrastructure in the U.S. and the Government's Role in Supporting Manufacturing Research and Innovation

Recommendation 1: *The President must establish a bipartisan blue ribbon panel to examine manufacturing and develop recommendations on government policies needed to support a more effective manufacturing infrastructure.*

Presenters at the workshop and NAE symposium noted that manufacturing companies invest heavily in R&D, and manufacturing provides critical support to our national defense systems. As U.S. manufacturing activities move offshore, these R&D activities will follow, causing the U.S. to lose its edge in innovation and systems security. Therefore, it is in the long-term interest of the U.S. to invest in and support manufacturing. This will also have an immediate positive impact, improving our employment of people with a wide range of skills.

The NSF workshop panelists recommend a blue ribbon panel be appointed by the President to develop recommendations on critical manufacturing policy and support issues, including: 1) coordinated manufacturing policies, 2) incentives and support for manufacturing R&D and job creation, 3) models and organizations for collaborative research, innovation and commercialization across industry, academia and government, and 4) education and workforce development for manufacturing.

Recommendation 2: *Establish a network or cluster of regional Manufacturing Innovation Centers, following the model of the Discovery-Innovation Institute (DII).*

The Discovery-Innovation Institute (DII) [7] was recently adopted by the Department of Energy to establish the Energy Innovation Hubs (http://www.energy.gov/hubs/) and is also an excellent model for manufacturing innovation. DIIs represent a network of competitively awarded large centers/consortia, with major federal funding, augmented by industry, universities, and investors to address transformational innovation and commercialization of critical technologies. DIIs, operated by a university or national laboratory consortia, help:

> "Foster partnerships to pursue cutting-edge, applications-oriented research among multiple participants and disciplines; develop and rapidly transfer highly innovative technologies into the marketplace; build the knowledge base and human capital necessary to address the nation's challenges; encourage regional economic development by spawning clusters of nearby start-up firms, private research organizations, suppliers, and other complementary groups and businesses"[7].

We believe that the issues inhibiting the advancement of manufacturing in the U.S. are so complex, involving socio-economic and technical issues, that the initiation of a functionally working interactive model such as regional manufacturing centers that bring together government, academic and industry leaders can truly affect real change. The recently released draft report from the Brookings Institute echoes this recommendation, advocating a National Laboratory for Advanced Manufacturing [8, 9].

Recommendation 3: *Enhance coordination of government agencies in funding manufacturing research and innovation.*

Current support for manufacturing research and innovation flows across several federal agencies, i.e., NIST, NSF, DoD, DoE. A consistent overarching message and maximum possible program coordination are important to raise public awareness and support for manufacturing. It is also vital that each government agency articulate the financial and strategic implications of the loss of manufacturing jobs and use the expertise to develop appropriate remedial opportunities.

Recommendation 4: *Create a component of the STTR and SBIR industry partner research program to solely support the application and commercialization of university research by small businesses.*

Innovative university research projects have produced results that are not being utilized by the domestic manufacturing industry, even when laboratory prototypes have successfully demonstrated irrefutable proof-of-concept validation. Examples include product inspection devices and systems that can be integrated into production lines to enhance productivity, reduce waste and improve product quality. There are many innovations, the result of long-term basic research, that are ready for implementation. These devices are not being added to existing production lines to boost the domestic manufacturing industry. Why? Typically, it is small suppliers who develop these laboratory prototypes into new industrially-proven machines. The building cost of these prototypes ranges from $300,000 to $700,000. A small company cannot afford this cost, particularly with limited production (8 – 12 machines would fill market demand). Large-scale manufacturers (e.g., an automotive company) typically will not engage until they are sure that a new machine is capable of working in a production environment. The end result is that valuable prototypes that could boost productivity and product quality remain in research laboratories.

The current STTR/SBIR programs do not fit this scenario. Phase I STTR requires basic research, which is not needed in these cases. We recommend a new STTR program that supports small companies with $300,000 to $700,000 grants, with 20% cash cost share by the large manufacturing company to "harden" the machine (or software) for its production use. This program will be used solely to design and build applications that will be integrated into a production line. Small companies will retain the knowledge, and the large domestic manufacturers (e.g., auto manufacturer) will benefit from the invention, paying only 20% of the cost (for the first machine) - both will boost the U.S. economy. If the end-use manufacturer needs more machines, they can negotiate the price with the small supplier who can estimate the exact cost, since they now have both the design and the implementation cost in hand.

This is the place where relatively small government support may make a substantial impact – better products for consumers, more profitable domestic manufacturers, and elevating the technology knowledge-base of small firms.

Recommendation 5: *Support small and medium-sized businesses with manufacturing modeling and simulation capabilities.*

The role of job creation by small and medium-sized businesses cannot be overemphasized, but such businesses do not have much capability in manufacturing process/system modeling and simulation. As suggested in a recent Brookings Institute report [9], support needs to be provided to the small companies in the supply chain where innovation more easily transfers into manufactured products. In addition, as discussed later in Recommendation 9, support for more open architecture products that will allow small companies to apply their innovative capabilities and enhance the functionality and manufacturability of products is needed. To facilitate this, the product modeling and simulation software used by large companies needs to be available to their suppliers to allow more effective interactions during the development of new products, and to avoid manufacturing problems in the supply chain later.

Develop Manufacturing Education Programs for K to Gray

Recommendation 6: *Change the image and vernacular of manufacturing.*

The general public perceives manufacturing jobs as "working the line." The loss of production line jobs and their low tech image have made the manufacturing profession less attractive to our very best young people. We cannot revitalize manufacturing until we create a new paradigm that makes engineering an attractive profession to the best students and the general public. Since manufacturing is associated with the design and realization of products, why not call it "Product Creation"? A good example of this is the software/IT industry's job title change of "programmer" to "software engineer" which attracts the very best students to study computer science.

Recommendation 7: *Develop a coherent manufacturing education curriculum.*

The fundamental need for education in manufacturing must be addressed by K-12 through expansion of pre-college, college/university and graduate education, and be heavily publicized through grants, prizes, media publicity, facilitated by national cooperation across universities, industry and government agencies and labs. Graduates at all levels should be able to gain new knowledge and tools using advanced learning technology and life-long learning programs. One important educational requirement advocated in the NAE report: "The Engineer of 2020" is that students be able to gain the "systems perspective" needed to deal with the complexity of contemporary manufacturing enterprises [10]. In particular, we urge that modeling and simulation methods become stressed at all levels of education to allow students to better understand the many factors that influence the outcome of any design in which they are involved. This view also has been stressed as essential to our national defense needs, in an NRC report that recommended: "DoD should ensure that its educational programs provide experiences in which students integrate the activities of modeling, simulation, analysis evaluation and communication to address real-world problems of importance to the consumers of the information" [11]. It also is important to restate the NAE's position that to gain the deep technical knowledge needed to work in a particular manufacturing domain, as well as have the broader systems knowledge needed to solve the very complex problems associated with manufacturing, is simply not possible in four years [10].

Recommendation 8: *Support collaboration in manufacturing engineering education across universities.*

Improvements and cultural evolution for manufacturing can be developed faster and better through collaboration. Universities across the country should collaborate in the education of master level students in manufacturing, providing open curricula, allowing students to take courses from different universities and participating in inter-campus projects. This approach provides opportunities for faculty/students from one university to learn from others, and gain efficiency in the delivery of educational programs. We believe this is particularly important in that manufacturing technologies vary considerably across regions of the country. The technological knowledge-base in Silicon Valley is quite different than that in the Great Lakes, and each can gain from the other.

Support Research in Open Architecture Products, Enabling Open Innovation, Collaboration, and Value Creation

Recommendation 9: *Provide support for research in technologies that enable implementation of open architecture products to spur innovations and value-creation by small-businesses.*

An open architecture product is one that allows components to be added to its original structure. For example, the PC has an open architecture. New hardware and software components can be easily interfaced with the PC to allow new applications. The iPhone has an open architecture that allows the addition of applications. In a closed architecture product the manufacturer designs and chooses the components, often limiting the options desired by customers.

Open architecture in products allows potential component developers to see inside the architecture without many proprietary constraints. The original equipment manufacturer (OEM) of an open architecture product publishes explicit standards and instructions that allow potential developers (usually small companies) to integrate their innovative components into the main product and create new features. For example, a cell phone can now also function as a camera, a GPS-aided guide, and powerful web access device. Open Architecture Products (OAPs) enable small companies to flourish (e.g., iPhone has thousands of application developers). These companies provide innovative components that integrate into the main product and adapt it to a new use. There are potentially many possible new applications, each with a small market share. The small market share is ideal for small businesses because the large corporations will not enter such markets. Therefore, an economy that encourages OAPs will bloom – the large corporations will produce the main product platforms and many small businesses will invent and produce hardware and software components.

The automobile interior may be an example of a new OAP [12]. Assume for a moment that customers will be offered the opportunity to design the interior of their new cars in a way similar to that of private airplanes where the interior is completely customized to meet the needs of individuals that use the plane. In such a scenario there would be a set of modules (e.g., storage compartments, microwaves, refrigerators, beds, etc.) that the customers could select from and arrange according to their preferences, subject to safety and manufacturing constraints. As a result, the interior of cars of the exact same model will look very different from one another.

Figure 2: Futuristic car interior (adopted from Y. Koren, "The Global Manufacturing Revolution," Wiley 2010 [12])

Make Sustainability a Business Imperative in All Phases of Product Life Cycle

Sustainable manufacturing adds value to the United States by increasing industrial competitiveness while protecting environmental resources for future generations. Two key aspects of sustainable manufacturing are under siege in the world today: national competitiveness and environmental quality. Increased profitability and competitiveness are currently being pursued by cost-reductions, most easily achieved by outsourcing to overseas production – which reduces the sustainability of U.S. manufacturing. This phenomenon has an impact on the environmental performance of manufacturing globally, since manufacturing abroad is subject to much less environmental control than in the United States. It is necessary for all enterprises to make sustainability a business imperative in order to maintain manufacturing in the U.S, create lasting employment, and protect the environment and natural resources for future generations.

The social, economic and environmental dimensions of sustainability are reflected in the equation below. The equation shows that sustainable manufacturing reduces environmental impact in the only manner possible in a world where the population is increasing and has an ever constant pursuit of higher standard of living.

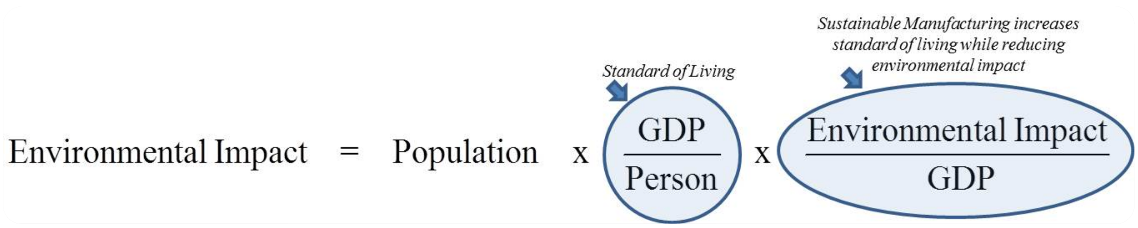


Figure 3: Sustainability Model

Recommendation 10: *Support re-manufacturing: including research into recovery methodologies, business models, logistics, quality assurance, and design for remanufacturing.*

Remanufacturing is a critical enabler of sustainable manufacturing. It can be thought of as a recycling process with the main difference being that instead of recycling material, remanufacturing recycles product functionality. This is achieved by disassembling products and then cleaning, repairing, replacing, and reassembling their components into products that are in sound working condition [13, 14] and often have enhanced functionality relative to the original product. Since new materials are not required, and remanufacturing processes have low capital costs and environmental impact relative to original production, remanufacturing can be a key to competitiveness as seen in the heavy equipment and consumer electronics industries today.

Remanufacturing requires a highly skilled workforce and can be labor intensive while being competitive, which helps to create jobs local to points of consumption. Remanufacturing therefore creates business opportunities for small and medium sized enterprises (SMEs), improves resource utilization, and reduces environmental impact. However, the workshop participants believe that remanufacturing has not reached its full potential in the U.S. due to the need for research into disassembly technologies, reverse supply chain logistics, design for multiple product life cycles, and quality/reliability assurance methodologies for remanufactured products.

Recommendation 11: *Develop and support implementation of engineering tools, standards and assessments, and certification systems for the life cycle impacts of products and services.*

Manufacturers must have tools that can help evaluate the life cycle environmental and social impact of a design, from concept generation, to materials selection, manufacturing, and the final end of life decision of the product. Such tools exist today, but they are not yet widely available to manufacturers. A lack of engineers who are knowledgeable and experienced in the assessment tools also inhibits the wide use of such assessment tools.

Enhance Manufacturing Systems Research

Recommendation 12: *Support further development and integration of models and databases used to simulate manufacturing system technologies, process operating conditions, and workforce capabilities to enable faster responses to the uncertainties in supply chains, workforces and market demands.*

The workshop participants agreed that one of the primary requirements to be successful as a manufacturing enterprise is to be able to quickly adapt to the uncertainties that exist in the market places and supply chains today. Our national defense also depends on this agility as stated in a National Research Council report: “To continue to perform well in the current economic climate, commercial manufacturers must be able to quickly innovate, design and produce the right product right the first time. Modeling and simulation technologies are important tools for achieving these goals” [11]. It also requires a manufacturing process technology that is highly adaptable across the supply chain, and one that is tightly integrated with the marketing and product development departments within the organization. It is realized that adaptability in low volume manufacturing systems often can be achieved by relying on the inherent flexibility of highly trained workers when provided with ergonomically designed working conditions, tools and equipment. But high volume manufacturing of top quality products must rely on automated processes that often are not highly reconfigurable.

To develop an understanding of the real costs associated with alternative manufacturing systems requires manufacturing organizations that can: 1) gather and statistically analyze the cost, quality and productivity data associated with existing operations, 2) develop valid estimates of the capabilities and limitations of existing and future workforce, software and hardware systems, and 3) utilize appropriate analytical models to simulate and predict the affects of alternative production scenarios. The following figure illustrates the three different major types of modeling that must be integrated and used together to provide an effective operations engineering system for manufacturing. It is proposed that such a systems modeling approach can facilitate a better understanding of the dynamic conditions affecting the firm, and thus enhance the ability of executives to manage uncertain supply chains, workforce skills, and demands for their products.

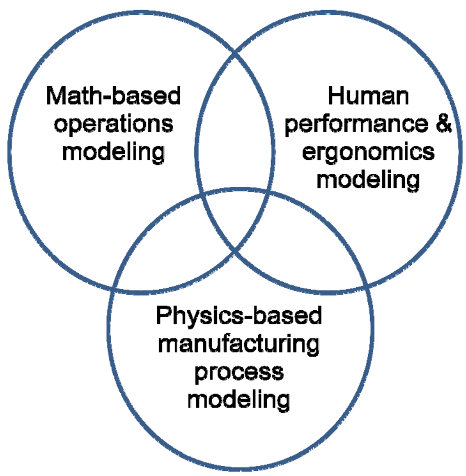


Figure 4: Illustration of three different types of models that must be integrated and used to provide the broad perspective needed to create a successful business plan to manage uncertainty in manufacturing systems, supply chains, markets and workforces.

Recommendation 13: *Support the development of improved logistical models and simulation methods to consider the combined costs of transporting raw material, parts and finished products, regional energy sources, and regional workforce skills and capabilities.*

Manufacturing and transportation of materials and products account for about 35% of the total U.S. energy use. A significant part of this is due to the requirement to transport materials, parts and finished products throughout the world. With the cost of transportation increasing, it is expected that more firms will distribute their manufacturing and final assembly operations closer to their parts suppliers and their marketplaces. In a qualitative sense, the development of distributed manufacturing facilities also allows more direct contact with customers through closely linked, local service organizations, thus improving customer loyalty and the ability to anticipate future market shifts. Also affecting decisions regarding facility locations is the recognition of large disparities in the regional cost of energy and certain types of raw materials. Considering such matters will require very sophisticated and new types of facility location, supply chain, and energy/materials utilization models.

Recommendation 14: *Support development of systematic methodologies in manufacturing scale-up.*

The workshop participants believe that there are a number of technical issues that often affect the ability of a firm to scale-up a new product. For instance, if the manufacturing of a new product requires metal parts to be joined together, there exist a large number of proven methods for doing this at both low and high volumes. Thus moving from a pilot plant, low volume operation to a commercially viable, high volume operation may be easily modeled with valid predictions for various production rates. Such may not be the case, however, when a new polymer is being used. Because of its unique new qualities, there may exist a general lack of knowledge about the surface chemistry necessary to accurately predict the strengths of various bonding agents commonly available and used in large volume manufacturing. Similarly, with the advent of nano-devices of all sorts, many of which involve exotic materials that must be joined in some fashion, the issues of scale-up from the laboratory to large volume manufacturing become even more difficult to manage. In addition, because many new materials and manufacturing processes are being developed, it is especially important to establish at low volume the potential health, safety, and environmental impacts of these new types of manufacturing operations before they are ramped-up to high volumes. Analytical models of new physical and chemical processes and materials are needed that can assist in managing the scaling-up of future manufacturing operations. Another example is the challenges we are presented in scaling-up the production green energy devices, such as batteries and solar cells, in large volume. Support for the development of manufacturing scale-up technologies will lead to quick commercialization and jobs.

Through collaborative efforts of researchers in the physics and chemistry of processes and those who are knowledgeable in quality assurance methods, throughput analysis, and operations engineering in general, new systematic manufacturing scale-up methodologies will be developed on a few select products. Such cooperative efforts should be documented in widely distributed public reports, thus providing a set of case studies and "best practices" to guide the scale-up of other new products.

References

1. M. L. Dertouzos, R. K. Lester, R. M. Solow and the MIT Commission, 1989, *Made in America – Regaining the Productive Edge*. The MIT Press.
2. Bureau of Economic Analysis (U.S. Government), (2009), http://www.bea.gov, Accessed, July 9, 2009.
3. Bureau of Labor Analysis (U.S. Government), (2010), http://www.bls.gov, Accessed, Jan. 30, 2010.
4. Office of the President, 2009, "A Framework for Revitalizing American Manufacturing".
5. NAE Forum Report, 2010, "Rebuilding a Real Economy" National Academy Press, Washington DC (p17).
6. Y. Koren, 1992, *Fundamental Research in Manufacturing for National Competitiveness – A Plan with Concrete Recommendations for Long-Range Economic Growth*. Workshop report submitted to National Science Foundation, March.
7. J. Duderstadt, G. Was, R. McGrath, M. Muro, M. Corradini, L. Katehi, R. Shangraw, and A. Sarzynski, 2009, *Energy Discovery-Innovation Institutes: A Step toward America's Energy Sustainability*, Metropolitan Policy Program at Brookings.
8. Susan Helper and Howard Wial, 2010, *Strengthen and Advance the Manufacturing Sector* in the report "The Next Economy: Rebuilding Auto Communities and Older Industrial Metros in the Great Lakes Region", Metropolitan Policy Program at Brookings (p.38), see www.autopaper@brookings.edu
9. Thomas Klier and Christopher Sands, 2010, *Support Innovation in the Auto Sector*, in the report "The Next Economy: Rebuilding Auto Communities and Older Industrial Metros in the Great Lakes Region", Metropolitan Policy Program at Brookings (p.36), see www.autopaper@brookings.edu
10. National Academy of Engineering, 2004, "The Engineer of 2020", National Academy Press, Washington D. C.
11. The Board on Manufacturing and Engineering Design of the National Research Council, 2002, "*Modeling and Simulation in Manufacturing and Defense Systems Acquisition*", National Academy Press, Washington D. C. (p.1).
12. Y. Koren, "The Global Manufacturing Revolution," Wiley 2010
13. http://www.reman.org/
14. Nabil Nasr, 2010, "*Reman for Success*", The Industrial Engineer, p26.

Appendix I

Engineering to Improve the Operations of Manufacturing Enterprises—NAE Regional Meeting at The University of Michigan

An NAE Regional Meeting and National Symposium entitled "Engineering to Improve the Operations of Manufacturing Enterprises" was held on April 13, 2010 at the University of Michigan. The public symposium was attended by 162 participants, which included 27 engineering students. Faculty and students from 23 different Universities were involved. The symposium was divided into five public sessions, followed by a meeting hosted by Charles Vest for the 24 NAE members in attendance. A formal dinner hosted by Dean of Engineering David Munson for all the speakers and NAE members concluded the day. The symposium agenda, biographical information about speakers and panelists, and videos of the major speakers can be accessed at: www.eiome.edu.

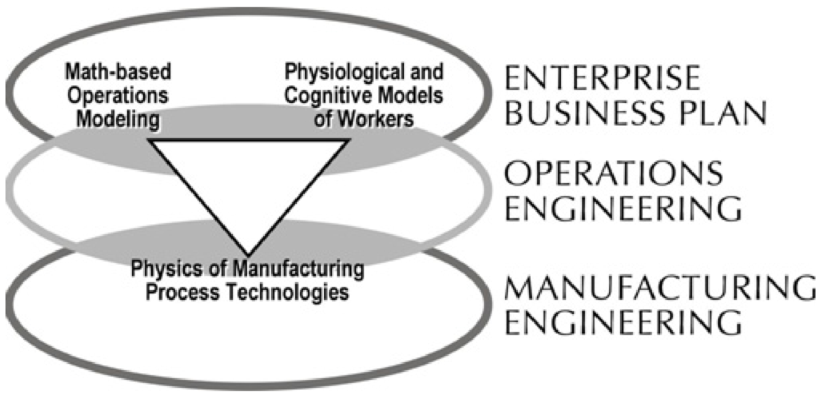
The Introductory Session at the symposium was lead by NAE member Don Chaffin, the R.G. Snyder Distinguished University Professor Emeritus at the University of Michigan (UM). Dr. Chaffin stressed that engineers involved in manufacturing need to be capable of using a variety of modeling and simulation tools to effectively consider the complexity of contemporary manufacturing operations in a global economy. NAE member and UM Vice-president for Research Steven Forrest and Dean of Engineering David Munson both emphasized in their remarks the importance of manufacturing to the Midwest, and the need for multidisciplinary and co-operative industry-academia programs of education and research to deal with the complexity of manufacturing operations today. Sridhar Kota, UM Professor on leave and currently serving as the Assistant Director for Advanced Manufacturing in the White House Office of Science and Technology Policy, pointed out that, although our nation leads in conceptualizing innovative ideas that originate in our impressive array of academic and national research laboratories, we fall short in effectively translating those ideas and research results into U.S.-based manufacturing of products and processes. The final talk in the Introductory Session was presented by NAE President Charles Vest who graphically illustrated the continuing decline in U.S. product manufacturing (now about 13% of GDP, involving less than 20% of workers). He emphasized that when a company exports manufacturing to another country, too often this is followed by an off-shoring of related technologies and with these goes the engineering leadership needed to sustain a U.S. presence in the market. He went on to state that we need to add 17 million new jobs in the next decade, and this will take a new generation in manufacturing technologies, robotics, and co-operative centers of manufacturing excellence in various regions of the U.S.

The next session, organized by NAE member Stephen Pollock, the Herrick Emeritus Professor of Manufacturing at UM, was on "Operations Engineering in Customer Driven Manufacturing". The keynote speaker was Dr. Larry Burns, former Vice-president of R&D and Strategic Planning at General Motors. Dr. Burns emphasized that the world is not "flat", but rather has great non-linearity, uncertainty, interdependencies, and complexities. A major requirement for a company to survive is to have a profound understanding of changing customer needs and wants. He emphasized that only with the aid of analytical models of their operations can the real value of producing certain types of products be considered early in the design process. He also added that only through careful modeling of the immense operations data available today can a firm steadily improve the quality and sustainability of their products. A panel of speakers then joined Dr. Burns. Professor Stephen Graves from MIT stated that the education of operations engineers to deal with complex manufacturing systems must include courses that emphasize decision making with uncertainties, advanced data analysis methods, and modeling that strives to optimize among trade-offs and constraints. Dr. Ulrich Raschke from Siemens Corporation provided videos that demonstrated how human digital models are being used to improve the ergonomics, safety and performance of workers by considering human-hardware interfaces issues early in the design of a manufacturing system. Lastly, Dr. Dev Pillai from Intel Corporation proposed that successful engineers must use analytical modeling to understand and resolve the complexities of today's manufacturing operations, and that various software applications are the key that allows teams of engineers and managers to effectively work together.

The third session of the day, organized by Wallace Hopp, the UM Herrick Professor of Manufacturing at UM, emphasized "Operations Engineering towards Green Manufacturing Systems". Dr. Sharon Nunes, Vice-president of Big Green Innovations at IBM, noted in her keynote address that we are about one-tenth of the way towards knowing how to design and operate truly green and sustainable manufacturing systems and that the protection of our environment requires collective actions that must be informed by systems thinking. Becoming "green" is an imperative. Energy usage, CO production, waste reduction, and GHG emissions can be measured, but only through statistical and economic modeling can these data be understood and used to inform effective policies. She noted that government regulations and customer demands will require the development of new operations models and policies to assure that manufacturing systems and supply chains are sustainable. A panel then joined Dr. Nunes. Joseph Wolfsberger, Senior Vice President, Environment, Health and Safety from Eaton Corporation, stated that striving to be a "green" power distribution company has gradually become a way of adding value within his company. This has been accomplished by reducing energy and water usage, improving safety, and assisting with community power line permit granting. Being "green" also improves their public image, their recruiting of skilled workers, government relations, and is providing new research and development opportunities. Dr. Steven Skerlos, Associate Professor of Mechanical Engineering at UM, added that only with mathematical models can the complexity of manufacturing technologies and their human and environmental impacts be understood. The public will demand that future products be completely recyclable, and this will require new manufacturing systems for new, environmentally sustainable materials. Dr. David Dornfeld, the Hall Family Professor and Chair of Mechanical Engineering at the University of California at Berkeley, discussed the importance of developing precision manufacturing systems that minimize waste and are highly efficient. This will require models of these systems to thoroughly understand how social, economic and technological attributes interact. Cooperative programs involving government, academic and industrial partners will be needed to assure engineering students have the tools and systems understanding needed to include sustainability early in the design of a manufacturing system.

The fourth session of the day was organized by NAE member Dr. Seth Bonder, President of the Bonder Group. The session was entitled: "Operations Engineering in Defense systems Acquisition, Manufacturing and Maintenance." The keynote speaker was NAE member General David Maddox, Ph.D., U.S. Army (ret.), who began by reminding the audience that the Department of Defense (DoD) spends about $200 billion on equipment annually. They use a life-cycle review process that relies heavily on models of proposed systems to demonstrate their operation under a variety of field conditions. He explained that the process begins with a DoD "statement of needs" that serves as the foundation for a potential manufacturer's proposal. The manufacturer is expected to use various models to design and verify that a proposed system can meet the military needs. Prototypes are built and more data gathered and modeled before a final design is approved for production. A panel of three speakers then joined General Maddox. The first panelist, Dr. Peter Cherry, Vice-president of Science Applications International Corporation, spoke about the growing complexity and shorter production timeframes required for new military equipment. Any new equipment must be fully compatible with military networking, and must have low energy demands. Only by using system modeling and simulation methods can new equipment be designed and produced that meet DoD needs. The second panelist was Mark McNitt, Manufacturing Technology Development Manager at BAE Systems, Inc. He acknowledged the importance of modeling and simulation methods in his company. He pointed out that team decision-making is often greatly facilitated by using sophisticated simulations of proposed new systems. One concern he has is that many of the software tools available today are not highly integrated. Further, getting smaller vendors in the supply chain to use appropriate modeling and simulation tools is often very challenging. The final panelist General Benjamin Griffin, U.S. Army (ret.), discussed the use of modeling of maintenance requirements. He stated that logistical issues are a major concern, due to high peak demands placed on repairing systems involved in combat. Other major issues involve the modeling of the time required to repair equipment, developing better spare parts inventory models, predicting the life expectancy due to preventive maintenance, and improving the design of the equipment to allow improved human performance while performing maintenance tasks.

The last session was a preliminary report of an NSF Workshop entitled: "Innovation and Operations of Manufacturing Systems". The workshop was organized by NAE member, Yoram Koren, a Distinguished University Professor at UM, and S. Jack Hu, the G. Lawton and Louise G. Johnson Professor of Engineering and Associate Dean for Academic Affairs in the College of Engineering at the University of Michigan. A complete report of this Workshop can be found at the NSF website: www.nsf.gov late in 2010.



Workshop participants:

Jeffrey Abell	General Motors Corporation
Jian Cao	Northwestern University
Donald Chaffin	University of Michigan (co-chair)
Josephine Cheng	IBM
Amy Cohn	University of Michigan
David Dornfeld	University of California Berkeley
Gary Fischman	Future Strategy Solutions, formerly National Research Council
Richard Furness	Ford Motor Company
Howard Harary	National Institute of Standards and Technology (NIST)
Thom Hodgson	North Carolina State University
S. Jack Hu	University of Michigan (co-chair)
Yoram Koren	University of Michigan (co-chair)
Thomas Kurfess	Clemson University
William S. Marras	Ohio State University
Gene Meieran	Intel Corporation (ret.)
Jun Ni	University of Michigan
Paul Nuyen	The Boeing Company
Jianjun Shi	Georgia Institute of Technology
Steven Skerlos	University of Michigan
John Sutherland	Purdue University
Bin Wei General	Electric Global R&D
Donald Winter	University of Michigan and former U.S. Secretary of the Navy