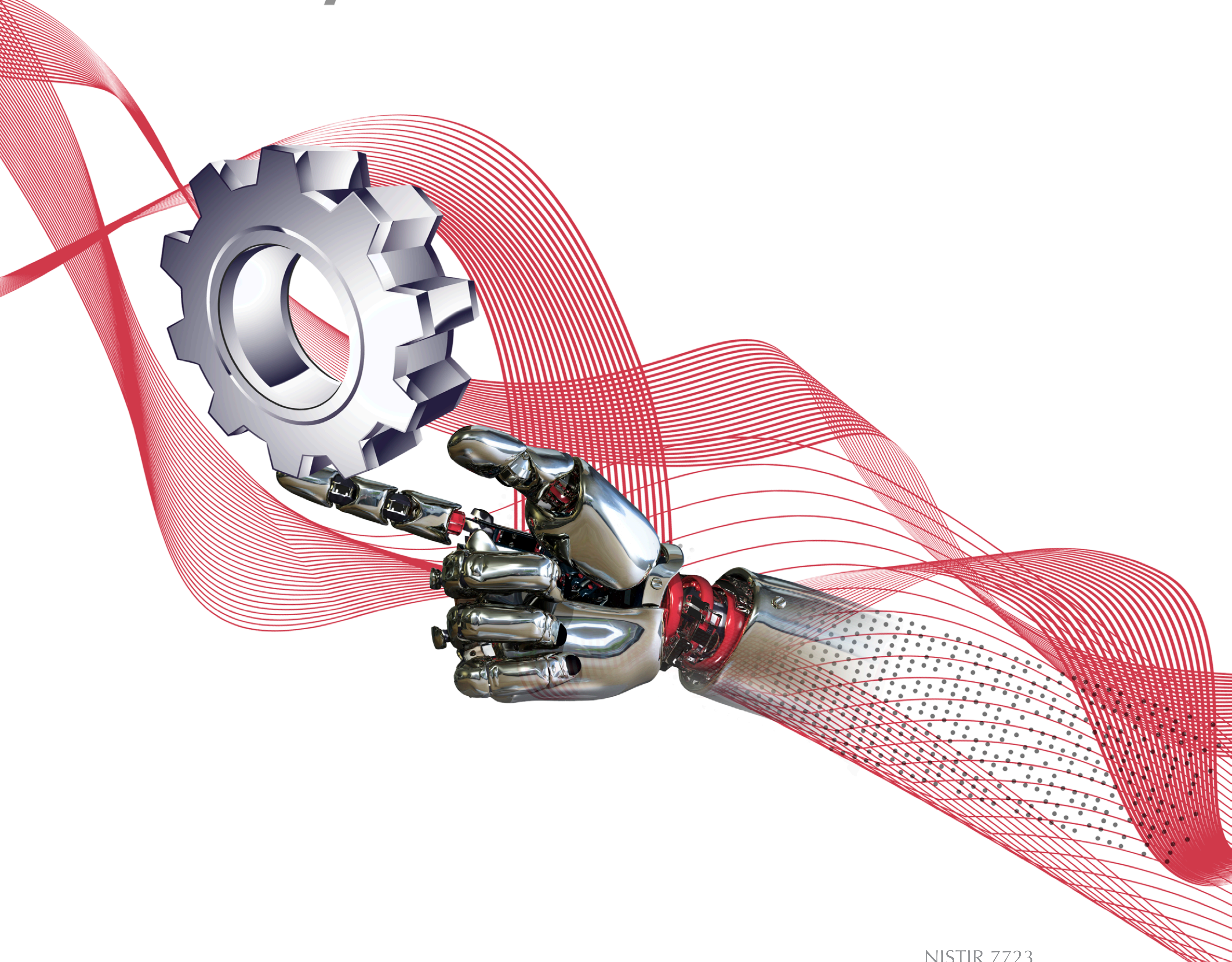
National Workshop on Challenges to Innovation in Advanced Manufacturing

Industry Drivers and R&D Needs



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Challenges to Innovation in Advanced Manufacturing:
Industry Drivers and R&D Needs

Final Report
of a Workshop Sponsored by the
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland

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Workshop facilitated
and report prepared by
Barry Lawson Associates
Peacham, Vermont

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Executive Summary

Representatives from manufacturers, academic research laboratories, the federal government and other organizations met on November 3rd and 4th, 2009 in Gaithersburg, Maryland to discuss the drivers that are encouraging companies and industries to introduce and develop manufacturing innovations. Attendees also identified major challenges to current and future manufacturing operations and their concerns for the future of manufacturing, including common challenges such as the availability of raw materials, the likely increased cost of energy, and the changing needs they have for data and data systems, models, standards and measurements.

Several dozen critical factors were highlighted from each of five topic-specific breakout sessions, spanning five principal areas of interest: Sustainability and Energy, Simulation and Modeling, New Manufacturing Processes, Manufacturing Information Technology (IT) and Interoperability, and Robotics and Automation. Among the most frequently mentioned **drivers to innovation** cited in the workshop were the following:

- Competition within industries, including competing companies located in other countries
- Perennial challenges to reduce costs and improve profits in the face of this competition
- The need to modernize and improve product quality and reliability
- Recognition of the benefits of increased flexibility in manufacturing production
- Requirements to comply with an increasing array of national and international regulations, standards and controls.

Considerable discussion centered on the short-term and long-term **challenges to innovation**. These included:

- Encouraging an overall revival of U.S. manufacturing with emphasis on education, workforce development, and corporate responsibility
- Integrating production models and production processes, enhancing capabilities to improve models and thus eliminate costly and time-consuming trial and error procedures, such as prototyping
- Pursuing enhanced interoperability and extending collaboration of production and the supply of intermediate products, both within individual plants and across companies' supply chains
- Maintaining a qualified and skilled labor force, including utilizing appropriate human resources where automation cannot fill the bill
- Capitalizing on the potential of automation to reduce costs, meet increasingly demanding standards to enhance quality, improve inspection processes, improve efficiency, and stress better intelligence and the optimization of manufacturing systems
- Promoting the concept of sustainability across plants and industries as an important goal, not only for corporate citizenship but as a long-term beneficial economic goal
- Developing standards that provide consistency, enhance integration, and reduce costs
- Projecting supply and demand for raw materials and the availability and potential use of new materials, including reliable substitutes where necessary
- Improving data collection, high-accuracy measurement technologies, and data management, as well as the protection of property rights, and security
- Improving simulation and modeling capabilities between model shops and plant floors to aid in reducing cycle times from concept to delivery and production costs

A major portion of this report is devoted to summarizing the major challenges and presenting a host of recommendations that evolved from the many discussions that occurred during the workshop. While the list of all the suggestions offered is not included in this report, its preparers have endeavored to identify those that seem to be the most relevant and viable.

An analysis of the results of the breakout sessions also yielded an array of issues that seem to have cut across most, if not all, the breakout sessions. These crosscutting issues are discussed in the report and include:

- Sustainability
- Standards and measurements
- Interoperability
- Data collection and management
- Models and simulation
- Agility
- Raw materials
- Reviving U.S. Manufacturing

Several workshop participants prepared papers for the workshop. They proved to be significant contributions to the overall discussion during the two-day session and are all reproduced as part of the report.

Analysis, Conclusions, and Recommendations

The results of the workshop will be circulated to attendees as well as to other interested individuals and companies who were unable to attend the workshop. NIST and other agencies will use these conclusions, which are based on consensus views of the workshop attendees, in their programmatic planning and development. It is hoped that these results will also be useful to companies, manufacturing engineers and executives, industrial associations, academic and other research groups, as well as to other government agencies that can assist and support innovations to manufacturing in the United States.

Workshop Structure

Purpose and Organization

The objective of the workshop was to identify the key industry drivers for innovation in advanced manufacturing technology and the measurements- and standards-related R&D needed to realize these innovations. Drivers, needs, and technologies that span multiple manufacturing sectors were of particular interest, as were the needs in infrastructural technology areas including measurements, performance metrics, test methods, and standards. Representatives from a number of manufacturing sectors and other manufacturing stakeholders present were encouraged to discuss current innovations initiated by their companies. This final report includes those infra-technologies that workshop participants identified as necessary to catalyze innovations in advanced manufacturing.

Participants and White Papers

A cross-section of leaders from representative manufacturing companies and associations from around the United States were invited to participate in the workshop. Seventy-seven people attended, representing diverse interests and organizations, including industrial, academic, and governmental. They shared a set of common interests, however, and the workshop program was designed to identify and discuss these commonalities, particularly as they related to the challenges to innovation in their respective areas.

Each of the invited participants was offered the opportunity to prepare a brief, two-page "white paper" in advance of the workshop. It was not the intent for these papers to be highly polished, formal, and of archival-quality, but rather to communicate thoughts and ideas simply and effectively. In crafting these papers the authors were asked to consider the following questions:

- What are key drivers for innovation in advanced manufacturing technology?
- What are the most important areas where R&D is needed -- particularly in measurement and standards -- to overcome barriers and accelerate innovation in manufacturing technology?

These papers reflected their authors' ideas and opinions relevant to the workshop objectives. The papers were assembled and made available to all participants prior to the workshop. Some of the white papers were selected for presentation at the workshop but all the papers received are reproduced in full in Appendix IV at the end of this report. The visual presentation of each of the five papers selected for the workshop plenary session can be found on the workshop's website: http://www.nist.gov/mel/advmanuwkshp.cfm.

Principal Issues – Background Questions

The workshop team, in structuring the two-day program, designed six questions to help focus discussion in the workshop breakout sessions. While each of these questions could easily lead the dialogue in several directions, the breakout session facilitators used these questions to help guide their respective discussions towards the identification of manufacturing engineering issues some, and perhaps many, of which would cut across industrial sectors. The white papers solicited helped to determine the six common questions listed below:

1. What are the major 'drivers' toward innovation in your company or industry? What related concerns keeps you awake at night? Let's differentiate between the 'macro' issues (e.g., world security, economic recession) and 'micro' issues (e.g., adjustments to your plant and machinery). Both types of issues may be significant.
2. What are the biggest technological hurdles you currently face in achieving improvements in your manufacturing processes?
3. What are the biggest technological hurdles you think you will face five years down the road, in achieving improvements to your manufacturing operations? How do you plan to overcome them?
4. How are you addressing the concerns for raw material supplies and higher energy costs (or more efficient energy use) in plant operations?
5. What are the major challenges you face (or successes you have had) in bringing those in your supply chain into synch with your company's technology goals and objectives?
6. What concerns does your company/industry have about the availability and quality of data, measurements and standards?

Workshop Program

Workshop Agenda

The complete detailed workshop agenda is in Appendix I. It provided a structure for the workshop that included opening and closing plenary sessions as well as breakout sessions for detailed discussion of the questions presented and other related issues. The agenda format was designed to maximize and promote interactions and discussion among participants, both in formal breakout sessions and during breaks and meals.

Opening Remarks

By Howard Harary, Acting Director of Manufacturing Engineering Laboratory and Barry Lawson, President of Barry Lawson Associates

- The opening of the plenary session on the workshop's first day began with a short introduction by Howard Harary, Workshop Chairman and Acting Director of the Manufacturing Engineering Laboratory (MEL). He noted that the purpose of the workshop was to focus on the challenges to innovation in advanced manufacturing, including identifying key drivers for that innovation and the key areas where industrial leaders believe that R&D is needed. He reminded attendees that NIST is particularly interested in standards and measurements and that the Institute stands ready to assist companies in meeting their challenges.
- Barry Lawson, whose firm provided neutral facilitators and note takers for the workshop and prepared this final report, explained the structure of the workshop and facilitated the plenary session. He introduced the five individuals who presented 10-minute overviews of their white papers as well as Vijay Srinivasan, who summarized the conclusions of an earlier NIST Sustainability workshop. Each presentation was followed by questions and comments from the workshop attendees.

White Papers Plenary Presentations

The workshop organizing committee selected the following five papers out of the thirteen white papers submitted. These were intended to help "prime the pump" for discussions during the two-day event. Each of these paper's authors was invited to present in the opening plenary session as well as to use it as a starting point in one of the breakout sessions. All of the submitted papers appear in Appendix IV at the end of this report. Several of the observations, ideas, and suggestions in these papers also influenced the common questions developed by the facilitators and the issues raised in the five breakout sessions. The following lists the plenary papers, along with a summary of their key theses and the relevant breakout sessions.

A. Sustainability and Energy

"Distributed Power - Aware Machinery as a Foundation for Next Generation Sustainable Manufacturing"

Dr. Fred M. Discenzo, Dr. Ram Pai, Dan Carnahan, P.E., Rockwell Automation

In order to compete in a dramatically changing manufacturing landscape, U. S. manufacturing leaders must demonstrate responsible behavior with regard to energy usage, waste disposal and recycling. The transition to sustainable manufacturing must be done in the context of increasingly complex manufacturing processes and related processes and enterprises. Organizations cognizant of these trends, and who accordingly shape their strategies and execute their tactics, will become the winners in the next decade. The ***integrated enterprise*** that effectively achieves process and personnel safety, environmental protection, and superior energy efficiency will realize faster time to market, lower total cost of ownership, excellent asset optimization, effective risk management, and economic excellence.

This paper outlines five critical drivers that will accelerate these changes, transforming virtually every manufacturing sector in the U.S. and seven areas of R&D needs that will provide the foundation for manufacturing success in 2025.

B. Modeling and Simulation

"Dual Manufacturing: Manufacturing Both Real and Virtual Products"

Dr. Michael Grieves, NASA Marshall Space Flight Center /University of Iowa

Product Lifecycle Management (PLM) is redefining the use of information throughout the product lifecycle and specifically in the manufacturing phase of that lifecycle. Manufacturers need to consider two products: the physical products that they have always produced and the virtual product that is the information about the physical product. This virtual product can provide manufacturers with a new source of value with myriad uses, not only in the manufacturing phase, but also throughout the product lifecycle.

C. New Manufacturing Processes

"Challenges in Net-Shape Manufacturing of Metallic Parts"

WT Carter, JS Marte, SR Hayashi, SV Thamboo, GE Global Research Center

The benefit of net shape processing to the U.S. manufacturing infrastructure is clear. It reduces wasted material and machining costs as well as energy and greenhouse gas emissions associated with production, transportation, and recycling of wasted metal. Such reductions would positively affect material sustainability and availability for high-tech manufacturing, and provide a competitive advantage for U.S. manufacturers.

The full benefits of net shape processing to the U.S. manufacturing infrastructure have not been exploited because of economic and technical challenges. This paper identifies progress that has been made in the following areas: net-shape deformation processes, material additive processes, and joining and advanced machining. It also presents recommendations for the R&D needed to overcome the challenges of net shape manufacturing.

D. Manufacturing IT and Interoperability

"Product Tolerance Representation: Critical Requirements for Product/Process Interoperability"

Curtis W. Brown, Engineer Principal Mechanical, National Nuclear Security Administration's Kansas City Plant1 and Daniel A. Campbell, Software Director, MetroSage, LLC

Current *electronic* product definition systems (i.e., CAD Systems) represent unambiguously *only a segment* of the product's design. Product tolerance presentations are generally of the form of mere textual annotations, devoid of any meaningful association to the product geometry. This gravely limits the designer's ability to create and communicate complete and unambiguous tolerance information efficiently, and it cripples downstream applications that depend on such information.

This problem could be resolved through the use of a full semantic representation of 3-D geometric dimensioning and tolerancing (GD&T), within or tightly coupled to the product definition system.

E. Robotics and Automation

"Ushering in the Next Generation of Factory Robotics & Automation"

Leandro G. Barajas, Ph.D., Manufacturing Systems Research Laboratory, General Motors R&D Center; Andrea L. Thomaz, Ph.D. School of Interactive Computing, Georgia Institute of Technology; Henrik I. Christensen, Ph.D., College of Computing, Georgia Institute of Technology

State-of-the-art, cost-effective Robotics and Automation (R&A) is vital in helping U.S. industry regain ground lost in the global market. Using the latest in dexterous and intelligent robotics and lean production technologies, next generation manufacturing assembly processes will provide the necessary competitive edge for affordable products and help retain jobs with shifts from line work to technical support and operation of the robotic systems. A new generation of assembly automation will reduce the current "robot capability gap" by exploiting the existence of a flexible robot perception system, a component of a three-part strategy including:

1) highly flexible robots/end effectors, 2) flexible perception, and 3) safe integration/harmony with people. Next-generation, "safe robots," will also substantially reduce R&A support investment.

Standards of performance and test methods are critical in the evolution of next generation R&A. NIST can assist by establishing system standards and evaluation metrics with specifications that encompass hardware and software metrology targets and high-level system qualitative and quantitative capability measurements.

Report: NIST Sustainability Workshop

NIST Sustainability Workshop –Vijay Srinivasan, NIST/ Manufacturing Systems Integration Division

Three weeks prior to this workshop, NIST sponsored another workshop focused on Sustainability. That event drew nearly fifty people representing a variety of companies in several industrial sectors to present and discuss current approaches that firms are making toward sustainable manufacturing. Because sustainability was anticipated to be one of several principal topic areas for this workshop, the workshop organizers invited Vijay Srinivasan, an organizer of the earlier workshop, to make a brief presentation summarizing some of the results and conclusions of that workshop. His report highlighted that sustainability: (1) is having a material impact on how companies think and act; (2) is a key driver of innovation; (3) must be viewed as an opportunity; and (4) can only be fully realized if many challenges, including the development of appropriate measurements and standards, are overcome.

Organization And Facilitation Of Five Breakout Sessions

Although the workshop began and ended in plenary sessions, the major discussions regarding drivers, challenges and recommendations took place in each of five breakout sessions. These sessions, facilitated simultaneously, provided an opportunity to subdivide the participants into areas of common interest for more personal dialogue. Note takers were present to record the principal ideas set forth in each of these five sessions, and facilitators provided guidance, focus on common questions and unique interests, and assistance in formulating summary statements that were reported back to the final plenary session.

Each breakout session, consisting of twelve to eighteen participants had a focus for discussion, and each of white papers prepared in advance featured a focus and perspective for one breakout session. As a result, the papers and their authors provided a valuable starting point for discussion. The facilitators and note takers worked closely together throughout the workshop to identify the issues that seemed to cut across most, if not all, the individual sessions. The answers to the common questions asked in each session provided an added degree of cohesion among the various groups.

The five breakout sessions were:

Breakout Session A:	Sustainability and Energy
Breakout Session B:	Modeling and Simulation
Breakout Session C:	New Manufacturing Processes
Breakout Session D:	Manufacturing IT and Interoperability
Breakout Session E:	Robotics and Automation

The results of the breakout session deliberations as well as the plenary summary sessions were then categorized for this report, not by breakout session, but by major topic and by which group (government, corporate, or mixed) was the most appropriate group to meet the identified challenges and to undertake the recommendations.

These results are presented on the following pages, by major subject area.

Results

The results of the workshop presented here reflect the discussions that developed in both the plenary and breakout sessions. Note takers recorded the principal points made in both types of sessions and those points have been analyzed and compared and then organized into three major components for this report.

The first component is the array of **crosscutting issues** that permeated the workshop sessions. These are the issues that were mentioned in most, if not all, of the breakout sessions and were, in effect, major threads that evolved from the workshop session. In fact, the importance of these issues as basic concerns is reflected in the use of these issues to help structure the challenges and recommendations starting on page 13.

The second component is the set of **drivers** identified independently by the workshop participants in each session. Some of these drivers were highlighted in the white papers prepared in advance of the workshop and reinforced in discussions. These drivers represented the principal factors that are creating the challenges, serve as the basis for many of the recommendations that follow, and are leading or pushing manufacturers to consider innovative changes in their manufacturing processes.

The third component of the findings in this report is the listing of **challenges and recommendations** from the workshop. The lists of both the challenges and recommendations are long, yet they represent the major points made by participants. However, the list of priorities does provide a starting point for highlighting actions that should be considered as next steps in strengthening the manufacturing sector in the U.S.

The challenges and recommendations have been further aggregated by those that seem to fit within the following three categories: those most relevant for the federal government, those most appropriate for consideration by manufacturing corporations, and those that call for collaboration between government and business and perhaps even require assistance from others as well.

Crosscutting Issues

Agility

Today's companies need to be agile in order to adapt to changing customer demand, foreign competition, declining natural resources and unforeseen world events. At present, implementation of agile production among companies and industries is uneven, particularly in the case of the smaller manufacturers. Agility requires science-based knowledge of product, processes and equipment. Factors leading to greater agility include flexible assembly systems, models and simulation, virtual products, personalized production solutions, and the consideration of movement towards the localization of manufacturing and innovation. Agile manufacturing is a basic component of innovation and sustainable manufacturing.

Sustainability

"The ability for U.S. manufacturers to meet today's needs without compromising the needs of future generations is the essence of sustainability," said one workshop participant. Long-term sustainability is the ultimate corporate innovation, with ramifications for every facet of business. It requires absolute commitment from corporate leaders and employees. Contentment with short-term profits, out-of-date equipment and tools, an inefficient supply-chain, and workforce limitations deter companies and industries from pursuing sustainable manufacturing goals. Many of the recommendations that follow in this report call for concern for the environmental and social "footprint" of a company as additional criteria (beyond profit) for success. Possible incentives for increasing awareness of sustainability initiatives included the creation of a new criterion for the Malcolm Baldrige National Quality Award or perhaps a completely new award.

Interoperability

Resolving interoperability issues, particularly throughout the manufacturing supply chain, is key to maintaining the strength of U.S. manufacturing and meeting global competition. There is an urgent need for cross-domain tools for industry-wide standardized languages; for standardized data formats and messaging capabilities among devices to harmonize systems; intelligent sensors; and improved data collection and control systems, as well as for increasing information on the value and impact of interoperability. There is also a desire to further increase the interoperability between CAD and CAM to exchange information among suppliers. Additional advances in this area could be realized with the development of window-based tools, open source systems, and customer consortiums to influence tool vendors.

Standards and Measurements

There is a strong call for more comprehensive standards in the field of manufacturing. At the same time, some participants expressed a lack of trust in the stability of standards in the present climate of rapid innovation. Manufacturers are asking for consistency among standards; for standardized methodologies, particularly in modeling and simulation; for more comprehensive CAD standards; and for the development and dissemination of best practices, guidelines, policies and definition of taxonomy. Other suggestions included the creation of test beds, a need for performance metrics, and the creation of a guide to current standards, including white papers demonstrating how to use standards that are already in place. Participants underscored the desire for government to lead the way in the adoption of standards across agencies for government procurement, with the belief that these standards will lead to faster resolution of interoperability problems.

Modeling And Simulation

The evolving technology of modeling and simulation is critical to the future of U.S. manufacturing competitiveness. Essentially every plant and industry is concerned with improved product models, while simulations aid in the reduction of cycle times from concept to delivery, and of production costs. Simulations can also identify important modifications in the manufacturing process to attain efficiencies in raw material consumption and energy usage. Virtual models that distinguish product information from the product itself will continue to become an indispensable means for predictive knowledge, risk management and product redesign.

Data

Innovation usually requires data management, data storage and data appropriate to the task. When considering data management, among the issues cited were propriety, intellectual property, security, trust, deception, standards, measurements and tolerances, and competition. Participants agreed that there is often a lack of reliable data to develop decision-making tools, for example, virtual product modeling or Life Cycle Analysis. A new version of STEP (STandard for the Exchange of Product model data, ISO 10303) was also cited as a requirement for innovation.

Raw Material Supply

Concerns on raw materials was expressed in each breakout group, with a focus on availability and cost of future raw material supplies and the identification or development of adequate, quality substitutes. There are international implications relating to foreign markets, export controls, and international regulatory compliance.

Reviving U.S. Manufacturing

This topic was of paramount concern in all of the breakout sessions. Suggestions in this area fell into four subtopics: Education, Workforce, Corporate Policy, and Government Support, all elaborated upon below.

Education

Manufacturing must be made more attractive to young people from the primary levels of education through the university levels. Increased funding will seed advanced research and innovation. The way we think about computers needs to change from serial, procedural thought, to parallel thought.

Workforce

Who will be trained for high technology work in the future is an overriding concern of U.S. manufacturers. Labor productivity is a critical issue and a moving target, with international competition being based on this factor. Paramount in this debate is the challenge of attracting more students to manufacturing and offering education, training (and re-training,) and apprenticeships, as well as addressing the loss of skills inherent in an aging/retiring workforce.

Corporate Policy

Education at the executive level will lead to increased support and funding for innovations for modeling and simulation, robotics, sustainability, etc. This, in turn, will help foster an environment that welcomes innovation, not only at the top but also throughout an entire organization.

Government Support: U.S. Policy and/or Department of Manufacturing

At the time of the workshop there was no explicit U.S. policy objective to support advanced manufacturing and no U. S. agency dedicated to directing and overseeing research and funding in manufacturing.[1] This is an urgent need, not only for the promotion of advanced manufacturing and innovation, but also for the support and promotion of an educated workforce.

1 Since the workshop, the Obama Administration has released "A Framework for Revitalizing American Manufacturing." (December, 2009)

Drivers To Innovation

The workshop explored the factors that influence innovation in U.S. manufacturing and what may be done to promote innovation. Manufacturing in this country has taken several hits in recent years – from the outsourcing of manufacturing to countries with lower labor costs, to adapting to changing consumer preferences. Other factors are in play, of course; but the net effect has been the loss of manufacturing jobs, a focus on short-term returns, and scrambling to find niche markets, all within a tight capital market and a severe reduction of consumer demand.

The workshop provided a productive forum for identifying these challenges as well as for discussing solutions to them. Moreover, the gathering helped to uncover other possible ways to help revive domestic manufacturing. This indeed was one of the significant results of the workshop. Session after session resulted in a list of possibilities for creative and innovative change.

In some cases, the work requires strategic planning and long-term investments. In other cases, it calls for assistance from researchers, for information sharing, and for contributions from industrial associations and government. It was argued that a successful manufacturing industry is in the national interest.

The following pages highlight these points and provide a list of initiatives, or innovations, that participants thought were worth considering in further detail.

In many companies, a successful (financial) bottom line is the number one goal. Without such success or promise of it in the near future, businesses simply drop by the wayside, get absorbed into more successful ventures, or restructure. Short-term viability is a principal and necessary goal; however, long-term viability is also critical. As discussed later in this section, many of the challenges to innovation relate directly to companies and industries not being able or willing to think long-term, especially to make the long-term investments that will ensure a competitive edge in the future. In some respects, the workshop was an initial dialogue on the long-term vision that businesses need to have, given the challenges and opportunities in current national and world markets.

The factors (or drivers) identified during the workshop can be categorized into six, somewhat interrelated groups.

Basic Economic Forces

Profit is typically the number one goal for business, not only for innovation but also for any capital investments, product development, and human resources management. While increasingly such phrases as the "triple bottom line[2]," "social responsibility factors," and the like are heard, the questions on how to lower cost, and increase profits and productivity tend to rule.

There are several aspects to the financial bottom line, including meeting or beating the competition, maintaining or increasing market share, considering short- and long-term returns, and the overall return on investment. Because this important financial bottom line reflects both costs and revenues, many aspects of manufacturing production come into play – whether it is raising capital for investment, developing a more productive workforce, improving product quality, lowering raw material and utility costs – all of which are concerns that capture the attention of manufacturers. Seeking innovative ways to improve a company's financial picture is fraught with many challenges, many of which will be highlighted in the next major section of this report.

Closely associated with the bottom line are the concerns and demands of non-investor company stakeholders. These include customers for products and services, companies on either side of the supply chain (suppliers and purchasers of intermediate products), neighbors, and social and industrial interest groups. All of these can and do place demands on the manufacturer - demands that have a direct effect on the bottom line. Addressing these demands, whether it is the development of niche markets or reducing a factory's effect on adjacent or 'downstream' properties, calls for innovation.

Another, more directly related set of stakeholders is a company's labor force. On one hand, the drive to lower labor costs has driven many companies' manufacturing production offshore for lower cost labor. On the other hand, there is an evolving crisis for companies who are finding home-grown skilled labor in shorter supply for a number of reasons, including the lower esteem that manufacturing jobs have in the United States. Finding ways to maintain a skilled labor force in this country is a critical driver for many of the workshop participants.

2 "People, planet, profit"

Quality of Product and Performance

Being competitive in the free marketplace demands a focus on the quality of the manufactured product and how it performs. What the consumer gets for the price charged is critical. How good and dependable is a product? Scrutiny in this realm increases on a daily basis. Consumer rating services, competitive forces looking for the best price or the best performing product, or the most dependable supply, all are related to the issue of product quality, its dependability or effective life, and efficient and cost-effective delivery.

Setting and meeting standards in the production and performance of products are related to quality. Innovations to differentiate a product and guarantee its performance, and agreements to provide service to maintain the product, drive companies to change and improve.

Energy and Raw Materials

Although a company's energy and raw material sources influence the corporate bottom line, other factors beyond cost are drivers for many companies. Some companies currently worry little about energy costs, according to some workshop participants. A primary reason: sweetheart deals that power companies have negotiated with large energy-consuming industries and plants. The incentive for being creative and energy efficient does not touch every company evenly. Yet, it will be the unfortunate plant that does not consider its costs and sources of power in the future. Innovation and creativity in the use of electric power in the future will be essential.

There are many factors to consider in the energy equation – emission controls, available and dependable sources, long-term energy efficiencies – and all of these are drivers for innovation. Many companies are taking steps to significantly reduce their total energy use. Others who have had less incentive to reduce their energy usage will at least start with basic conservation measures, i.e., shutting off lights and equipment when not necessary; developing ways to integrate power systems, locating close to a power plant or generating their own power, and selling excess power back to the grid. Energy conservation appears to be a major opportunity for creativity and cost savings.

The availability of raw materials is also a major factor driving companies to innovate. Challenges include dwindling world supplies and the associated higher costs, questionable availability due to global demands, and the need to find or develop cost-effective substitutes. This is an ongoing process for most manufacturers. The drive to be innovative is significant, and can lead to major changes in production processes and in the products themselves.

Meeting Government Regulations; Providing Public Incentives

Frequently, social concerns, expressed in the form of government regulations, serve as significant drivers for innovation for industries. Among the most familiar regulations are labor laws (including health and safety; environmental controls and limitations), product liability laws; and export controls. Meeting or exceeding these regulatory limits is an important driver of innovation.

Government incentives in the form of direct subsidies, publicly supported research, government purchase of products, tax breaks for new plant construction, and tax credits to stimulate socially-responsible investments all provide incentives, or drivers, for companies and industries to innovate.

Sustainability and Corporate Social Responsibility

Sustainability is an increasingly important and popular driver for many U.S. companies. Sustainability may mean different things to different manufacturers. A definition that emanated from the workshop seems appropriate: “meeting today’s requirements without compromising the needs of future generations.” Implicit in this definition is the concept of long-term sustainability of the company along with limited adverse impact on workers, neighbors, natural and energy resources and the environment. This is an ideal goal perhaps, and one that a small, but increasing number of (primarily small) companies are embracing. These companies have found that considering both environmental and social effects can be a positive boost to the traditional, single bottom line. For these companies sustainability is a major driver.

Very much related to sustainability is corporate social responsibility. Mentioned ocassionally during the workshop, social responsibility is an intermediate stage in the drive for sustainability. It is an awareness and concern for all that touches or is touched by a company. Other countries have embraced social responsibility more fervently than the United States, but there are significant exceptions. Achieving corporate social responsibility and seeking sustainability are two drivers that affect many aspects of a manufacturing concern.

Safety, Security and Protection of Intellectual Rights

Protecting the property rights of a company - the unique qualities of its products and their performance - can directly affect the company’s competitive edge. Threats to this protection can come from the sharing of data in the supply chain to working in other countries that have no intellectual property rights laws. Data sharing can lead to better efficiency along the supply chain, so finding ways to do it in a fair and safe manner is a driver with many challenges that will be explored in the next section.

Concern for the health and safety of workers and users of manufactured products drive innovations across American manufacturing. Security at a different level of magnitude has come to the forefront in the past decade in response to potential terrorism. The need for security, which would include protection of products in transit, drives the search for innovative devices, advanced security systems, and new regulations and controls.

Challenges to and Recommendations for Realizing Innovation

Workshop participants identified many challenges to promoting and supporting innovation in U.S. manufacturing. These challenges are summarized in the following pages, organized around subject areas that evolved from the workshop and the papers prepared for it.

Some of the most basic challenges can only be met with a strong contribution, and often a leadership role, from the federal government. The first group of challenges in each subject area, therefore, relates to considerations at the national level. The second group focuses on corporations, and the third group concerns either a combination of government and corporate or challenges to other entities (e.g., industrial associations).

To meet these challenges, workshop participants offered many recommendations. The ones chosen for this report are those that were heard most often and/or were perceived by the workshop facilitators and note takers as most relevant. Some of the recommendations address one or more of the challenges identified, and not all of the challenges necessarily have an obvious, directly related, recommendation identified. These recommendations are presented in boxes that follow each list of challenges in each section.

Overall Challenges at the Federal level:

- The federal government does not sufficiently recognize that it is in the public interest to have a solid, dynamic and creative manufacturing sector. This includes an educated and trained workforce, capital markets, sufficient independence for private enterprise in critical areas, and support for standards, tools, data management and regulations.
- The federal government does not adequately understand the importance of having a manufacturing sector that is competitive in world markets, not for all products and services perhaps, but for many critical industries and products for which the country can have a comparative, if not absolute, competitive advantage.
- Despite NIST and other Department of Commerce efforts, there is no one agency devoted to supporting manufacturing in the United States.
- There is not enough support for research and development and pilot programs in more sophisticated data management, simulation and modeling and intelligent systems to support manufacturing processes.
- Particularly in the current economic climate, innovation requires a variety of tax credits, research and development grants and loans, and other assistance.
- Greater support is needed for selective import controls and for navigating the range of international export controls to support and encourage U.S. manufacturing.
- The federal government doesn't sufficiently recognize the direct connection between having a strong domestic manufacturing sector and maintaining military security.
- The federal government should be prepared to assume the following critical roles:
  - Assess the areas in which U.S. manufacturers have (or could realistically have) comparative advantages in the world market;
  - Provide research and technical assistance grants and tax credits to support the diffusion and adoption of innovations at the corporate level;
  - Establish guidelines and standards to assist industries and companies in revitalization; and
  - Help industries navigate the international labor, raw material, and product markets.

Overall Recommendations at the Federal level:

Recommendations:

- Establish a strong national manufacturing policy at the highest levels of government, a policy that sets out goals and a national strategy for attaining them – not unlike the NASA initiative begun decades ago.
- Designate an agency within the federal government that has the lead responsibility and accountability for implementing the above national strategy, and that coordinates the participation of many federal agencies and the integration of programs that contribute to this implementation.
- Encourage partnerships that include government assistance/tax credit/capital devoted to investment in capital equipment and the development of new tools to help U.S. manufacturing maintain its role as a world leader.
- Create a U.S. Department of Manufacturing to support all aspects of U.S. manufacturing and to help the country maintain its role as a world leader in this area. The Department of Commerce is a logical option; but whatever agency plays this role, a review of existing mandates and capabilities to perform the role(s) is necessary. Efforts to restructure, re-orient or eliminate existing programs and introduce new ones must be supported by the executive and legislative branches. This also applies to other agencies with roles to play in this endeavor. Identifying this federal "team" and creating an appropriate way for that team to work together in pursuing a common strategy is a critical element.
- Promote collaboration among appropriate agencies and between the federal government and the manufacturing establishment. Provide incentives for companies and industries to move away from the focus on short-term monetary profit because it inhibits long-term innovation and goal setting. Help small businesses take a longer-term view of innovation.
- Create federal and state government initiatives that encourage companies to work towards a common goal and to further public appreciation of the benefits of maintaining a healthy manufacturing sector in this country.

Sustainability

A major element of the strategy for a reinvigorated and innovative manufacturing sector is a commitment to long-term viability and to a "sustainable" economy, which emphasizes economic success, but not at the expense of national goals related to environmental and social values and international responsibilities and concerns, such as national security, climate change, globalization, and human welfare.

In order for sustainability to take hold in this country, there must be corporate commitment. The principal aim of such commitment is to empower individual companies and industries to assume a new perspective on success, to "invest" in innovative strategies, and buy into a new era of corporate responsibility.

A host of challenges to pursuing sustainable manufacturing were expressed during the workshop. Many of these challenges require a new outlook, a new paradigm and philosophy about manufacturing and the role of the individual company within society. Many companies are not yet prepared to accept these challenges; but this should not stop efforts to work toward a new paradigm. In fact, working toward that paradigm can improve the financial bottom line of a company.

Challenges in and Recommendations for the Pursuit of Sustainability

Government

- Standards compete to frustrate, rather than harmonize to facilitate, sustainability goals;
- Industries are not inspected often enough on meeting emission standards, as are automobiles;
- Younger generations lack enthusiasm for participating in making American manufacturing viable and sustainable;
- There is insufficient correlation between manufacturing sustainability efforts and national energy independence goals and the Smart Grid;
- Toolkits (such as those from The Organization for Economic Cooperation and Development, OECD) for corporate and manufacturing sustainability have not been adequately disseminated or expanded;

Recommendations:

- Focus government assistance (e.g., tax credits, grants and loans) on infrastructure with a goal toward sustainability.
- Recognize industrial examples of excellence in sustainable manufacturing – one possibility being adding criteria to the Malcolm Baldrige Award.
- Develop a universally appropriate definition of sustainable manufacturing and a national goal towards achieving it. These are essential to ensuring consistency and integration between public and private sectors and among various industries.
- Develop and disseminate case studies where companies have successfully pursued sustainability goals.
- Establish and/or fund pilot programs to explore methods and techniques that companies can adopt in their pursuit of sustainable manufacturing.
- Assist small companies in designing and utilizing affordable and accessible simulations that help in adopting innovations for more sustainable manufacturing.
- Expand the OECD toolkit for corporate and manufacturing sustainability.
- Promulgate strong regulations on national and international scales that protect people and other living organisms in the environment and that do not inappropriately favor one company or one country over another.

Corporations

- Manufacturing is undervalued in the United States, and the country is behind Europe in intelligent and sustainable manufacturing.
- Senior management lacks commitment to sustainability strategies and greater corporate social responsibility.
- Businesses are unwilling to make changes in plant infrastructure and to support systems that have positive long-term benefits, such as more agile manufacturing processes, because they may undercut short-term profits.
- Finding new ways to reduce wastes and emissions and promote cost-effective recycling programs is difficult.
- Companies have not adopted a "triple bottom line" approach - encompassing social and environmental, as well as financial criteria and incorporating this information into annual reports to stakeholders.
- Companies are not doing enough in conducting energy audits and analyzing life cycle costs to foster understanding of where innovations or changes in operations are appropriate.
- Companies are not doing enough to minimize wastes and their disposal that cause both short- and long-term adverse environmental impacts.

Recommendations:

- Develop manufacturer sustainability plans that incorporate every aspect of a plant's operation – from procurement to production – from supply chain to marketing and distribution.
- Undertake life cycle analysis and assessment programs at the company level and apply life cycle and integrative planning throughout a company's supply chain to strengthen and support interoperability and sustainability.
- Create a sustainability "philosophy" and discipline that can be applied to plant operations and be embraced by industrial leaders and senior plant managers.
- Create sustainability plans that seek to reduce emissions and wastes, minimize the use of raw materials, promote worker and product safety, and strive for greater energy efficiency.
- Consider adopting a "triple bottom line" to reflect the commitment to sustainable operations and corporate responsibility.

Joint Corporate/Government

- The full range of traditional and alternative energy sources is not being considered, including co-location with energy sources and cooperative programs with other energy users.
- More agile and sustainable manufacturing practices can represent a major step toward producing high-quality, higher-value products, but this is not adequately recognized.

Recommendations:

- Design risk models that provide the insight for making choices that embrace sustainability as the overriding long-term goal.
- Develop sustainability certification programs, such as Energy Star, to help manage energy use, and utilize eco-labeling – with criteria that reflect the long-term goal of sustainability - for tools and equipment and industrial process improvements.

Modeling and Simulation

Being innovative means thinking creatively, considering options, being open to new ways of conducting business, and researching ways to use or create sophisticated hardware and software tools. Modeling and simulation can be major tools in the innovation toolbox. All interests need to be knowledgeable of the critical role that models can play in helping companies to be creative. Government has a large role to play in supporting modeling and simulation, whether it be supporting research, setting appropriate standards, or disseminating information. Here are the challenges and some recommendations from the workshop participants for modeling and simulations.

Challenges in and Recommendations for Creating and Using Models and Simulations

Government

- More research and development are needed to develop pilot programs in simulation and modeling to support the manufacturing processes.
- Accessibility of modeling and simulations to small manufacturers is limited because of high costs.
- Developing sophisticated models, simulations and creating virtual designs often depends on accurate, high quality and precise data and validation, which are lacking.
- How something is modeled is not always transparent to the user.
- Models by themselves do not necessarily ensure good products.
- There are security issues related to transferring data and design models throughout a supply chain - valuable property rights might be compromised.

Recommendations:

- Develop guidelines for accuracy, precision and transparency in simulations and models to ensure high-quality products. ("If you can't measure it, you can't manage it.")
- Develop standards, regulations and guidelines to promote high quality, accurate data in models and simulations to help determine the risk, cost and inherent problems in product development.
- Create economic stimuli, tax breaks and government funding to make modeling and simulation affordable to small manufacturers.
- Develop a standard, consistent interface that contains certain concepts regardless of the tool (such as the cut/paste feature in all word processing programs).
- Promote standards for building and validating models, including a focus on best practices and harmonization.
- Provide funding for research projects that can have important ramifications for small businesses, which, alone, are unable to make such investments.

Corporations

- Companies often fail to recognize that it is less costly to discover problems in the early stages of product development, and that virtual modeling programs can greatly assist in such discovery.
- Virtual designs are underutilized in cutting costs and economizing on materials during product development.
- Virtual modeling is underutilized for improving interoperability in a company's supply chain and for promoting cooperation between model designers and plant production workers.
- Risk and cost models to plan systematically for future resource use are underutilized.
- Companies are not using product life cycle analysis and modeling to help get a holistic view of the various elements of the production process.

Recommendations:

- Use virtual modeling to design and exchange transparent models that can share data, information and production modules all along the supply chain and promote cooperation between model designers and plant production workers.
- Design and/or employ models and simulations to use real-time data and databases to optimize raw material use, reduce waste, and improve the product quality.
- Develop virtual modeling programs to assist in problem identification and to cut costs in the early stages of product development.
- Integrate modeling and simulation into the tools that companies already use.
- Develop means for exchanging data and information among production modules as needed to develop product simulations throughout the supply chain.
- Address the need for assembly analysis of models—either by software or by people.
- Recognize the value of creative workers because model building is often an art as much as it is a science.
- Utilize risk and cost models to plan systematically for future resource use.

Joint Corporate/Government

- Company executives are not well educated about the value of modeling and simulation during product development.
- There is not currently a highly trained and skilled workforce that can design and use increasingly sophisticated simulations and models.
- Risk models for making choices that embrace sustainability as the overriding long-term goal have not been designed.
- Designing and employing models and simulation using real-time data and data-bases (e.g., intelligent systems) are not widely available or used to optimize raw material use.
- The usability and interface of tools does not allow for personalized natural language (i.e. the language of the customer).

Recommendations:

- Encourage government, private and public initiatives and partnerships to support pilot programs and multidisciplinary research in simulation and modeling of manufacturing processes.
- Develop white papers and case studies on modeling and simulation targeted to company executives, to increase their awareness of the value of these tools.
- Develop government, business and educational initiatives to train and/or retrain a workforce to design and use sophisticated simulations and models.
- Create a clearinghouse of information and/or a standardized framework for modeling and simulation to stimulate use among more manufacturers. These could be linked into the public domain.
- Provide technical training and recruit skilled computer-based modelers who can create and manage models and simulations that are essential for innovation, whether they be on the administrative, marketing or production sides.
- Design risk models for making choices that embrace sustainability as the overriding long-term goal.

Robotics and Automation

The workshop devoted a specific section of the program to discuss the role that Robotics and Automation could play in reinvigorating U.S. manufacturing. One problem, however, is that the robotics industry has not gained a strong foothold in this country, certainly not as it has in other countries, notably Japan and Germany. Therefore, the challenge is twofold: getting the robotics industry better established in the U.S. and using it for innovation.

Challenges to and Recommendations for Strengthening the Contribution of Robotics and Automation

Government

- There are no standards or specifications for determining noise/variation/motion in a measurement, assuming near-perfect dimensional quality, measuring uncertainty or randomness, nor methods or procedures for calibrations of cameras and robots.
- There are few industry-consensus performance measures for robots and other equipment.
- There are no standards or certifications for robots and automation systems.
- The country lacks a manufacturing and technological policy that will trickle down into schools, businesses, and professional associations, and also lacks support systems for advanced manufacturing, including robotics and automation.

Recommendations:

- Create a manufacturing and technological policy -- National Innovation Foundation, Science Technology Innovation and Diffusion policy -- that will trickle down into schools, businesses, and professional associations to support existing systems and to bolster public support for advanced manufacturing.
- Create standards and measurements for robots and other equipment that focus on performance rather than design.
- Include intelligence software and its integration into a national policy.
- Establish an agency of the government dedicated to funding research on manufacturing automation, including support for relevant university efforts.
- Create a policy to define how robotics and automation fit into the supply chain, both working collaboratively or solo.
- Develop guidelines, white papers and other specifications to help manufacturers integrate robots into existing manual operations.
- Focus increased funding towards engineering of robotics and automation.

Corporations

- Robots from different manufacturers must be able to work together, via interoperable systems
- The manufacturing industry has not yet determined how robotics and automation fit into work within the supply chain.
- Manufacturers have not fully and holistically integrated robots into existing manual operations/assembly/work.

Recommendations:

- Be aware of the research being undertaken regarding the development of robotics and the introduction of automated systems in production processes.
- Provide wireless, energy-efficient power for industrial applications on the plant floor and explore technical advances to satisfy the large power consumption needs of industrial robots.

Joint Corporate/Government

- Funding for research, development, integration and innovation for all aspects of robotics and automation is lacking.
- Industry is not able to make maximum use of actuators and genius sensors
- Industry is currently unable to model complex robots with higher dimensional mechanics. Models and simulations for robot and automation systems are inadequate.
- Wireless power for industrial applications on the plant floor is not available.
- Industry and educational institutions do not collaborate in robotics and automation research.
- Public awareness to generate more interest in robotics and automation is lacking.
- There are not enough incentives for workers to seek education and employment in the field of robotics and automation.
- Robotics is a multi-disciplinary field, and thus it is difficult to find dedicated/directed funding in this area.
- The public perception of manufacturing in general, and robotics in particular, is neutral or negative.

Recommendations:

- Identify sources of funding for research, development, diffusion and innovation for all aspects of robotics and automation, including software development, sensors, actuators with high power density, flexible perception, dexterous manipulation, social interface/interaction between humans and machines (including safety), high-level cognitive abilities, generation of automatic behaviors for repetitive tasks, high power density actuators, high degree of freedom manipulators in modeling and in control, and design and control of compliant (non-stiff) robots.
- Create a consortium to address standards and certification for robot and automation systems. NIST could help with standards development, and a third party could certify.
- Create more and smarter sensors, including genius sensors that are self-calibrating and self-aware, plug-and-play-sensors, sensors that are more easily re-programmed and which distribute sensing responsibilities across systems of sensors
- Educate the public about the use of robotics by creating partnerships between universities and industry and publicize their work. Increase the public's understanding of robotics, through the creation of national center that has the equivalent high-visibility of an Apollo program or National Institute of Health (NIH). Expand the National Science Foundation to be a national science and technology foundation.
- Create guidelines or specifications that enable robots from different manufacturers to work together, particularly in the areas of robot vision, manipulators and communications.
- Research practical solutions for modeling complex robots, including higher dimensional mechanics and complex simulations.
- Encourage research to determine noise/variation/motion in a measurement, to measure uncertainty or randomness, and to develop methods or procedures for calibrations of cameras and robots.
- Create grant opportunities for academic liaisons with industry (GOALI) to pursue joint projects on robotics and automation between universities and industry, making research and outcomes public. Allow both to keep some intellectual property.
- Support robotics for young men and women at the secondary school level through robotic competitions (games or grant proposals) and university and industry partnerships with high schools.

Data and Data Sharing

Data, data collection, data sharing, data quality and reliability, and data use were integral topics at the workshop, particularly in reference to the role that data plays in the design, calibration and evaluation of models that can be used in businesses to generate and support innovation. Many of the current issues revolve around the data that is now collected and the relevance and dependability of that data.

Moreover, the need to share data (and models) with others, particularly in a company's supply chain, raises a whole set of other issues, often in the context of protection of intellectual property rights and the threat of competitors gaining access to confidential data. Some of the challenges and recommendations that concern standards and measurement will appear in a later section.

Challenges and Recommendations Related to Data and Data Sharing

Government

- There is need for models and simulation to use real-time data and databases to optimize raw material and energy use.
- Virtual designs are not being used sufficiently to work out design and production problems early, before actual production occurs.
- There is currently no national advocate for the establishment of data standards.
- Increasingly complex models will require much larger data storage capacity.

Recommendations:

- Review intellectual property issues that affect the sharing of data to facilitate interoperability within supply networks without compromising a company's competitive advantages.
- Support training and retraining of the evolving labor force to take advantage of the availability of new data management, simulation and modeling programs.

Corporations

- In some cases there are no methods for transferring data and design models throughout a supply chain while ensuring the protection of valuable property rights.
- Not enough attention is being given to the quality of data used in models and simulations– among them consistency, accuracy, reliability, applicability and cost.

Recommendations:

- Explore ways to promote trust between manufacturers and suppliers in the broadest meaning of the term – who, for instance, has access to data and when should they have access.
- Invest in improved and reliable data collection (including measurement) essential for developing sustainability models.

Joint Corporate/Government

- There is inadequate funding for pilot programs in data management, simulation and modeling, robotics and automation, and intelligent systems that support manufacturing processes.

Recommendations:

- Solicit support through government agencies, research organizations, and appropriate partnerships for research and development to support pilot programs for more improved applications of data management, increased application and sophistication in simulation and modeling, robotics and automation, and intelligent systems that support the manufacturing processes, including the following: (1) Visualization tools for understanding impacts and prioritizing efforts for modeling and simulation; (2) A new version of STEP; and (3) Case studies to model appropriate use and storage of data among supply chain partners.
- Develop open source programs for data management to promote the sharing of data throughout the supply chain.
- Create a clearinghouse for information and data to help in the adoption of innovative strategies for data collection, application and storage.

Interoperability

One of the major themes of the workshop was the importance of interoperability within a manufacturing supply chain. Among the keys for realizing interoperability are data and virtual modeling, such that all those along the supply chain are aware of, and can respond appropriately to specifications based on a common and mutual knowledge of the final product. This includes factors such as dimensions, composition and performance qualities, and tolerances. Companies bear the brunt of the challenge of being interoperable. For many, this will mean transforming the production and material supply process dramatically and developing new models based on better and more reliable data and data collection.

Challenges to and Recommendations for Enhancing Interoperability in Manufacturing

Government

- Government is not supportive enough of interoperability and the promotion of agile manufacturing as key innovative steps in streamlining supply chains. There have been no studies on the impact of greater interoperability on the manufacturing sector.
- Interoperability is where the requirements for accurate data and measurement and for creative modeling and automation come together, allowing for more agile manufacturing processes and a more sustainable approach to manufacturing. Government needs to understand this.
- Government is not sufficiently active in supporting and disseminating information to encourage interoperability.
- There is not enough financial support for innovations to enhance interoperability within manufacturing processes.

Recommendations:

- Study the value and impact of adopting procedures that promote interoperability for companies or an industry in a manner that can be shared by all stakeholders along the supply chain to promote more agile and sustainable manufacturing.
- Embed intelligence in data in a way to allow it to flow to other systems including to the shop floor.
- Include interoperability in compliances such as ISO 9001 to eliminate the need to regress to pencil and paper.
- Support CAD-CAM (Computer Aided Design-Computer Aided Manufacturing) as a means to show CAD data, and find ways to diminish the cost and encourage implementation, especially of downstream users.
- Initiate a pilot project to standardize data formats and software to resolve issues of exchanging information between modules of different product simulations to demonstrate that this is technically feasible and to overcome cynicism.

Corporations

- There are no procedures to promote interoperability within a company's supply chain that can be shared by all and that promote common understanding, cooperation and consistency throughout the supply chain.
- There is concern that sensitive data about a product will be used by those in the supply chain to help competitors.
- Companies are not widely using virtual modeling, consistent standards, measurements and tolerances to increase interoperability within the supply chain.
- Having information incompatibilities within the ISO 9001 system sometimes means that people have to rely on "paper and pencil" approaches, rather than being able to use more sophisticated electronic analyses (e.g., Excel.)
- Value and safety are threatened because of "translation" problems between manufacturing software, especially supposedly compatible CAD/CAM systems.
- Companies have not figured out how to balance security issues with interoperability.
- Companies are not showing CAD data to people who need to see it.
- It's difficult to share information between different product simulations modules.
- There is not a marketplace for data exchange similar to RosettaNet for small shops with software underpinnings.

Recommendations:

- Apply life cycle and integrative planning throughout a company's supply chain to strengthen and support interoperability.
- Design and develop sustainability plans that incorporate every aspect of a plant's operation – from procurement to production – from supply chain to plant operation.
- Design and develop transparent models and product simulations that can be shared within the supply chain to promote shared understanding and cooperation among those involved.
- Develop standards all along the supply chain to identify errors and problems as early as possible.
- Work toward interoperability between CAD and CAM to allow the passing of information among suppliers.

Joint Corporate/Government

- Security protocols often run at cross-purposes in the drive toward interoperability.
- There are problems with STEP that, if addressed, would promote greater use, diminish cost, and validate accuracy.
- Protocols for power-aware machines used in in-shop planning and scheduling are outdated.

Recommendations:

- Create a richer STEP so that more vendors will use it. Solve problems of overly large files, especially when translated, reduce the cost of implementation, make it more user-friendly, make sure that standards keep up with the technology, and most importantly, certify that the machine is telling the truth.
- Research and create guidelines for exchanging important information without compromising a company's competitive advantages.
- Develop protocols and define and create modeling software for power-aware machines used in in-shop planning and scheduling, thus allowing for better energy monitoring, planning, and usage.
- Create a data exchange marketplace for small shops. Consider including an area for specific bids in the "National Innovation Marketplace," a third party player in the Job Shop Network, and, within MEL (NIST's Manufacturing Engineering Laboratory), explore hooking up the "plug and play" opportunities with suppliers' networks.
- Create a consortium of supply chain companies to conduct common research and share solutions to common problems for the mutual benefit of all in the consortium.

Energy

Overseeing the drive toward more efficient use of energy, diversifying the sources of available energy, and securing greater energy independence for the nation is the role of the federal government. This mandate has been in place for years, but much work remains to be done. Industrial energy consumption represents about one-third of total energy use in the country, so identifying and meeting the challenges in the manufacturing sector requires leadership to transition to a new and more comprehensive way of looking at energy use.

Many companies have embraced energy efficient ways of doing business, primarily as an economic measure. Other companies, often benefiting from low-cost energy arrangements, have taken relatively few steps to be energy conscious. This will inevitably change.

Challenges in and Recommendations for Pursuing Greater Energy Efficiency

Government

- Government is not making a strong enough connection between sustainability and the national goal of energy independence as a major element of national security.

Recommendations:

- Embrace and encourage such new technological advances as the Smart Grid, and tie sustainability efforts to national energy independence.

Corporations

- Companies are not fully using energy audits and analysis of life cycle costs to discover areas where innovations or changes in operations are appropriate.
- Increasingly complex models may require additional computer storage capacity.
- Many companies fail to reduce long-term costs by considering ways to be more energy efficient.
- Companies are not considering the full range of traditional and alternative energy sources, co-location with energy sources, and cooperative programs with other energy users, and are not identifying the lowest cost energy source(s).
- Companies fail to integrate energy management with throughput and quality, so that all too often it has become an after-thought.

Recommendations:

- Take immediate and relatively simple steps toward energy conservation that might save 10-15 % of energy use. Identify the biggest users of energy at the plant level.
- Reduce energy costs through comprehensive audits and appropriate investments in intelligent monitoring systems, best management practices, and new technology such as integrating with evolving “smart grids.”
- Everything on the plant floor has an energy impact. Install low-cost intelligent sensors to measure (and perhaps manage) energy use and waste, including measuring the energy function at the machine level as well as point-to-point in the production process.
- Apply life cycle and integrative planning throughout each company’s supply chain to strengthen and support interoperability.
- Undertake energy audits, not only of plant operations, but also of each stage of the supply chain, including the extraction of raw materials.
- Establish energy-use criteria to guide the planning and implementation of improvements in-line with long-term sustainability.
- Synchronize machines to run at non-peak hours, as practical, and develop “sleep modes” for machines.
- Adopt certification programs, such as Energy Star, to help manage energy use.

Joint Corporate/Government

Recommendations:

- Define energy use criteria to guide the planning and implementation of improvements that are in consonance with long-term sustainability.

Raw Materials

Considerable workshop attention focused on the challenges related to securing raw materials for manufacturers, especially in this era when many of these are procured in the world market. The changing and competing demands for materials, especially from other countries, provides a backdrop that requires government cooperation and leadership for innovative and creative approaches. Manufacturers, of course, have the basic challenges in responding to the availability and cost of raw materials used in their manufacturing processes, as well as contemplating the use of substitutes for improved product performance or perhaps because of the uncertainty of maintaining a dependable supply of an important material.

Cooperation will also be essential in studying the world markets for raw materials as well as researching new candidates for substitute materials. Reducing waste, setting realistic goals for reuse and recycling, and perfecting the production process to minimize trial and error will also be important. Cooperation in establishing international agreements and long-term contracts will involve both the private and public sectors.

Challenges in and Recommendations for Securing Raw Materials

Government

- Government is not adequately assessing factors that affect the world raw materials market for the next 20-25 years.
- Government is not providing enough support for developing long-term international and bilateral contracts and agreements to support the manufacturing industries' technical, raw material and energy needs.
- Manufacturers that depend on rare earth materials need to compensate for this dependence by better planning 20-25 years in advance for where those rare materials will be found, or, more likely, what for substitute materials may be available.

Recommendations:

- Participate in and assist companies in developing long-term contracts for raw materials from other countries.
- Promote the use of Enterprise Resource Planning, or something similar, to assure consistent, dependable supplies of raw materials.

Corporations

- Companies often don't identify the source of raw materials used in various stages of production to create transparency and interoperability.
- To ensure product performance, users may require knowledge of how it was assembled and of the raw materials that were used in manufacture.
- Companies are not actively pursuing re-manufacturing through buy-back or take-back programs that may be cost effective and reduce raw material costs.

Recommendations:

- Extend the use of intelligent systems throughout the supply chain, including the extraction of minerals and other raw materials, with regard to cost and environmental impact.
- Analyze the extent of raw material waste in the total production (and recycling) process and participate in recycled materials and product reuse initiatives.

Joint Corporate/Government

- Manufacturers need help in anticipating the availability of raw material and the world's market, especially if it is difficult to learn the origin of (and trace the process of acquiring) those materials.

Recommendations:

- Develop a system of metrics to 'score' raw materials according to their capacity to be reused or recycled and their degree of scarcity and toxicity. Score alternative raw materials also according to their flexibility, reliability, and performance characteristics.
- Analyze the effects of import regulations on manufacturers, especially the Berry Amendment and International Traffic in Arms Regulations (ITAR) that affect their ability to procure materials for national defense purposes from other countries.
- Develop and use risk and cost models to plan systematically for future resource requirements.

Standards and Measurements

Standards that set the basis for almost all aspects of manufacturing will be key ingredients in the overall strategy for re-invigorating the nation's industrial sector and implementing the innovations required to achieve that goal. All of the areas considered above require, in some way, a review and analysis of existing standards and their impact on manufacturing. New or revised standards will almost assuredly be required.

It is at the corporate level that most standards and measurement requirements get implemented, so it stands to reason that companies should avail themselves of opportunities to influence them. The challenges include those that could simplify or rationalize interoperability initiatives.

Challenges to and Recommendations for Improving Standards to Facilitate Innovative Practices

Government

- Some current standards are out of date and some are difficult to comply with.
- Variations between international standards and U.S. regulations affect U.S. manufacturers.
- It is often too costly for companies themselves to establish standards in cooperation with others in the same or related industries.
- Industries need help in promulgating industry-wide standardized language, including industries that cross national boundaries.
- The development of performance standards for products has been neglected in favor of focusing on design standards.
- No one is promoting standards for building and validating models, including those that focus on best practices and the harmonization of standards.
- Some factors require better or improved measurement other than the so-called "carbon footprint."
- Standards are not being implemented due to the cost, poor interaction among many software programs and other resistance.
- CAD standards are not comprehensive enough and need to be updated.
- Manufacturers are not convinced of the benefits of STEP.
- There is no semantic web for product data to interface with standards.

Recommendations:

- Prepare a 'white paper' to serve as a guide on how to use standards that are currently in place that affect manufacturing. Develop a pilot demonstration project for a prototypical architecture for a manufacturing enterprise showing how standards can be used.
- Create a taxonomy for scoring alternative raw materials according to their flexibility, reliability, and performance characteristics, their ability to be reused or recycled, and their degree of scarcity and toxicity.
- Develop design and production standards and tolerances and apply them all along the supply chain to identify errors and problems as early as possible, to ensure greater consistency in the production process.
- Create data collection standards for equipment to help predict machine errors and to detect reasons for failures that include a time correlation with the data collected from different machines.
- Create a semantic web for product data to interface with standards.
- Develop, promote and enforce international standards for the protection of workers from poor working conditions, unsafe machinery, and handling hazardous material.
- Expand current CAD standards to make them more comprehensive.
- Address the need for a common manufacturing model of IT, and define how to address gaps.
- Work with federal agencies to develop a pilot project that demonstrates the use of standards and prove that the process can be used with the Department of Defense.
- Develop a cost metric for standards so that end users can see the benefits of STEP.

Corporations

- Companies struggle with the fact that specification sheets from different suppliers for the same product can be different, and this can affect quality and performance. The gap between those specifications and the realities of what is produced is too large.
- Manufacturers don't trust the stability of standards, and are reluctant to embrace new versions of software.
- Manufacturers don't understand Product Life Cycle costs, which have not been adequately described, measured or projected, especially because of regulations.
- Companies don't understand how to use the standards that are in place currently.

Recommendations:

- Invest in more, better, and more reliable data collection (including measurement) essential for developing sustainability models.
- Explore the use of low-cost intelligent sensing and measurements to understand and control energy use and minimize waste.

Joint Corporate/Industry

- There are no design and production standards and tolerances to ensure greater consistency in the production process.

Recommendations:

- Develop sustainability certifications for tools and equipment and industrial process improvements.

Appendices

I - Detailed Workshop Agenda

II - Workshop Organizing Committee

III - List of Participants

IV - White Papers

V - Information on Key Participating Organizations

Appendix I: Detailed Workshop Agenda

"Challenges to Innovation in Advanced Manufacturing: Industry Drivers and R&D Needs"

Workshop Sponsored by the National Institute of Standards and Technology
Manufacturing Engineering Laboratory
Gaithersburg, Maryland, November 3-4, 2009

Program

Tuesday, November 3, 2009 – First Day of Workshop

Time	Activity(ies)
8:00-8:30 AM	Arrival, Registration, Assignments and Administrative Information
8:30-10:30	Plenary Session – "Setting the Table" • Welcome and Purpose of the Workshop – MEL Acting Director Howard Harary • Roles of facilitation team and workshop procedures – Barry Lawson, Barry Lawson Associates • Assignment of participants to each of five break-out sessions • Ten-minute presentations of selected white papers, with clarification questions (see below) • Report from the October 2009 NIST Sustainability Workshop
	Papers: **G. Sustainability and Energy** "Distributed Power–aware Machinery as a Foundation for Nest Generation sustainable Manufacturing", Dr. Fred M. Discenzo, et al., Rockwell Automation **H. Modeling and Simulation** "Dual Manufacturing: Manufacturing Both Real and Virtual Products", Michael Grieves, NASA-MSFC/University of Iowa **I. New Manufacturing Processes** " Challenges in Net-Shape Manufacturing of Metallic Parts", Judson Marte, GE Global Research Center **J. Manufacturing IT and Interoperability** " Product Tolerance Representation: Critical Requirements for Product/Process Interoperability", Curtis Brown and Daniel Campbell, NNSA and MetroSage **K. Robotics and Automation** "Ushering in the Next Generation of Factory Robotics and Automation", Leandro Barajas *et. al.*, GM, and Georgia Institute of Technology **L. Report: NIST Sustainability Workshop** NIST Sustainability Workshop – Vijay Srinivasan, NIST/Manufacturing Systems Integration Division

Time	Activity(ies)
10:30-10:45	Short Break
10:45-12:00	Break-out Sessions – facilitation - *Barry Lawson Associates* • Introductions and procedures • Brief review of the white paper prepared for each session by author – with clarification where necessary • Common questions that each session is asked to address • Begin substantive discussion
12:00-1:00 PM	Lunch (in assigned breakout sessions)
1:00-3:00 PM	Breakout Sessions (continued) • Facilitators pose common questions, then lead discussion on participant perspectives and ideas on what's needed to encourage and support innovations in manufacturing • Seek agreement where possible, noting differing opinion
3:00-3:15	Short Break
3:15-4:30 PM	Breakout Sessions (continued) • 10-minute summary by facilitator of progress • Address any remaining questions • Develop consensus on answers and ideas for actions participants would like to see • Develop an agreed-upon summary of each group's progress to be delivered back to plenary session
4:30-5:15	Plenary Session • Each facilitator (or other representative from each break-out session) makes a five-minute report to a plenary session on progress toward answers to questions posed as well as other ideas and observations groups wish to share • Brief discussion and preparation for second day
5:15-6:00	Break
6:00-6:30	Reception and Cash Bar
6:30-7:30	Buffet Dinner

Wednesday, November 4, 2009 – Second Day of Workshop

Time	Activity(ies)
8:00-8:30 AM	Arrive and relaxed discussion Posting of any changes in schedule, availability of summary from Day One
8:30-9:45	Breakout Sessions (same alignment as in the first day) • Working from results of the first day, complete the questions (if necessary), consider possible modifications, identify factors that could influence actions (by NIST and/or others) to address actions needed – lack of information or capital, lag in research, efforts by others, etc. • Develop first-cut list of priorities among actions to be undertaken
9:45-10:00	Short Break
10:00-11:45	Breakout sessions (continued) • Final discussions in breakout sessions. • Draw conclusions on answers to questions, actions needed to address goals of agile and sustainable manufacturing, other factors the groups feel important to underscore
12:00-1:00 PM	Lunch – informal discussions
1:00-2:00	Plenary Session • Final 10-minute reports back to full plenary session. • Opportunity for final comments on key points made (or not made) during the workshop
2:00	Adjourn Workshop
2:15-4:30	Optional tours of NIST facilities

Appendix II: Workshop Organizing Committee

Dr. Howard Harary (Workshop Chairman)	**NIST**
Dr. John Slotwinski (Workshop Coordinator)	**NIST**
Albert Wavering	**NIST**
Elena Messina	**NIST**
Kevin Jurrens	**NIST**
Dr. Barry Lawson	**Barry Lawson Associates**

Appendix III: List of Participants

Name	Organization	Title
Dr. Jorge Arinez	General Motors R&D Center	Staff Researcher
Dr. Leandro Barajas	General Motors R&D	Staff Researcher
Dr Dean Bartles	General Dynamics	Vice President & General Manager
Mr. Bruce Borchardt	NIST	Metrologist
Dr. Michael Burstein, EMCP, CEI	Society of Manufacturing Engineers	International Director
Daniel Campbell	Metrosage	Software Director
Dr. Barbara Cuthill	NIST Technology Innovation Program	Impact Analyst
Eric Detlefs	Sandia National Laboratories	Manager
Sha-Chelle Devlin Manning	Zyvex Labs	
Dr. Alkan Donmez	NIST	Group Leader, Machine Tool Metrology
Roger Eastman	Loyola University	Associate Professor
Richard Echenrode	BAE Systems	Project Engineer
Dr. Ronnie Fesperman	NIST	Mechanical Engineer
Dr. Steven Fick	NIST	Electrical Engineer
Nathan Forbes	GE Global Research	Business Development Manager
Lisa Fronczek	NIST/MEL	Science Advisor
Dr. Mike Grieves	NASA MSFC	
Dr. Howard Harary	NIST, MEL	Director, MEL
Dr Martin Hardwick	RPI & STEP Tools, Inc.	
Jack Harris	Rockwell Collins	Director, Advanced Manufacturing Technology
Dr. Rob Ivester	NIST/Program Office	Program Analyst
Mr. Kevin Jurrens	NIST	Acting Division Chief, MMD
Sharon Kemmerer	NIST	Deputy Division Chief, MSID
Bob Kiggans	SCRA	Chief Operating Officer & President, Federal Sector
Kevin King	National Tooling & Machining Association	Manufacturing Technology Director
Dr. John Kramar	NIST	Group Leader
Dr. Barry Lawson	Barry Lawson Associates	Principal
Mrs. Silvia Leahu-Aluas	Sustainable Manufacturing Consulting	Owner - Principal Consultant
Mr. Kang Lee	NIST	Group Leader, Sensor Development and Application
Swee Leong	NIST	
Georege Lo	Siemens	Automation & Control Dept. Head
Kevin Lyons	NIST	Research Engineer
Jud Marte	General Electric	Metallurgist
Jennifer McAllister	Rockwell Collins	Manager, Adv. Operations Engineering
Richard McDaniel	Siemens	Research Scientist
Charles McLean	NIST	Guest Researcher

Name	Organization	Title
Ms. Elena Messina	NIST/Intelligent Systems Division	Acting Division Chief
Dr. Young B Moon	Syracuse University	Associate Professor
Dr. Shawn Moylan	NIST	Mechanical Engineer
Dr. Nagen Nagarur	Systems Science and Industrial Engineering Dept., Binghamton U.	Chair
Mr. Richard Neal	IMTI, Inc.	President and Executive Director
Dr. Ram Pai	Rockwell Automation	Director
Lalit Patil	University of Michigan, Ann Arbor	Research Fellow and Lecturer
Mr. Marc Pepi	Army Research Laboratory	Materials Engineer
Chris Pfeifer	Connecticut Center for Advanced Technology	Applications Engineer
Margaret Phillips	NIST/Technology Innovation Program	
Dr. Michael Postek	NIST/MEL/Procision Eng. Div.	Division Chief
Mr. Fred Proctor	NIST/Intelligent Systems Division	Group Leader
Dr. John Randall	Zyvex Labs	Vice President
Mr. Thomas Rose	AvPro, Inc.	President
Mr. Gary Sera	Texas Engineering Extension Service	Director
Dr. Michael Shneier	National Institute of Standards and Technology	Perception Systems Group Leader
Jon Siudut	Binghamton University	
Dr. John Slotwinski	NIST	Strategic Planning Manager
Dr. Johannes Soons	NIST	Group Leader, Manufacturing Process Metrology
Vijay Srinivasan	NIST	Chief, Manufacturing Systems Integration Division
Mr. Raj Talwar	The Boeing Company	
Greg Tassey	NIST	Senior Economist
Sam Thamboo	GE Global Research	
Brian Tucker	University of Alabama in Huntsville	Research Scientist
Steven Turek	Air Force ManTech	
Dr. Shuji Usui	Third Wave Systems	Lead Developer
Marlon Walker	NIST/Technology Innovation Program	
Wencai Wang	University of Michigan	
Mr. Paul Warndorf	AMT - The Association For Manufacturing Tech.	Vice President - Technology
Al Wavering	NIST/MEL	Deputy Director, MEL
Mr. Jack White	VRC/TTGSI	VP

Appendix IV: White Papers

Distributed Power-aware Machinery as a Foundation for Next Generation Sustainable Manufacturing

Dr. Fred M. Discenzo, Dr. Ram Pai, Dan Carnahan, P.E.
Rockwell Automation

I. Introduction

The U.S. manufacturing landscape is changing dramatically. Future markets will favor manufacturers that demonstrate responsible behavior with regard to energy usage, waste disposal and recycling. To compete, future manufacturers must maximize economic value-add from intellectual and physical capital investments, operate as part of a larger ecosystem of linked environmentally responsible global customers, suppliers, and partners. True leaders of tomorrow will play a global leadership in innovation of novel products and solutions. The transition to sustainable manufacturing must be done in the context of increasingly complex manufacturing processes and connected processes and enterprises. Organizations that are cognizant of these trends and accordingly shape their strategies and execute their tactics will define the winners in the next decade.

II. Critical Drivers

The events surrounding 9/11 coupled with recent worldwide financial instability, aging workforce, volatility and insecurity of world energy supplies, and the need for environmental stewardship foreshadow an onslaught of a dramatic shift in values and priorities that is beginning to transform how consumers behave and manufacturers operate. Changes in technology, public policy, world security, and the financial and energy markets changes are among the factors accelerating the change in manufacturing. We see five major drivers that are transforming virtually every manufacturing sector in the US. These drivers are:

No	Drivers	Expectations
1	Energy & Waste	Effective utilization of resources to reduce waste and energy consumption, while optimizing production.
2	Safety & Security	Inherent Security and Safety of human, physical and intellectual capital across the connected supply chain.
3	Social Responsibility	Assessment and availability of information on Carbon and GHG emissions across the Product Life Cycle.
4	Harmonized Standards	Supply chain integration with availability and automated interpretation of digitized global standards across interoperable systems.
5	Globally Linked Enterprise	Global communication supporting a fabric of enterprises capable of exchanging and making decisions on information in real-time across the globe.

II. R&D Needs

Specific developments are needed to efficiently promote the transition to a new manufacturing paradigm. There are seven areas of R&D need that will provide the foundation for manufacturing success in 2025. These areas are:

No	R&D Needs	Scope of Development Required
1	Sensing and measurement	Cost effective distributed sensing for energy, waste, process fluids, and airborne chemicals. Sensor fusion & wireless-self-powered sensors coupled with smart sensor networks.
2	Modeling & Simulation	Design and operational (i.e. control) models for sustainability
3	Dynamic link to plant manufacturing equipmdent and energy sources	Standards to support dynamic grid interface and linkages to plant MES and level 0/1 plant control to drive sustainable manufacturing and optimal economic performance.
4	Knowledge	Standardized approach needed for encoding process and product information –critical gap now beginning to occur.
5	Distributed energy & energy storage	Reference implementations based on Smart Grid standards to accelerate the adoption of energy aware eq. & processes.
6	Manufacturing Technology	New Pinch and other manufacturing with less energy, smart energy-aware machines and controllers, more efficient OEM equipment.
7	Methodologies for agile integrated manufacturing	Vertical and horizontal integration capabilities to support demanding requirements for capturing core capabilities and integration of those capabilities up and across the supply chain Mechatronics standardization and integration.

The topic area noted as "***Methodologies for agile integrated manufacturing***" is considered foundational and will form the cornerstone for future sustainable manufacturing. It is essential to provide a standard framework for distributed plant machinery such as ovens, fryers, boilers, fans, pumps, and other process equipment to exchange information on energy and process information in real-time and to respond to dynamic information provided by the grid in a timely and coordinated manner. This permits unprecedented capabilities for dynamically altering plant operations in an effective way to protect productions processes and safeguard machinery and personnel while achieving targeted energy usage and manufacturing sustainability objectives. A representative framework for smart distributed energy-aware machines is provided by distributed agents. This framework, based on a biological analogy, has a rigorous underpinning and has shown to provide superior performance in a variety of complex and critical manufacturing processes[1]. There is a need to explicitly embed standard energy, risk, and economic protocols to permit this open, integrated system to dynamically link process equipment with plant scheduling and machinery control. As shown in the plant diagram multiple distributed processes must be coordinated and scheduled in real time to achieve new performance levels in energy utilization, waste reduction, and sustainable production. The scope must include plant facility services, supply chain partners, energy providers and customers.

V. Summary

Recent events have triggered an irreversible change in manufacturing and necessitated the rapid transition to environmentally sustainable and socially responsible manufacturing. The ***integrated enterprise*** that effectively achieves process and personnel safety, environmental protection, and superior energy efficiency will realize faster time to market, lower total cost of ownership, excellent asset optimization, effective risk management, and economic excellence. These factors will determine the winners in U.S. manufacturing in the next decade.

[1] "Intelligent Systems: Architecture, Design, and Control", A.M.Meystel, J.S.Albus, John Wiley & Sons, Inc., New York, 2002

Innovations in Energy Measurement and Control for Manufacturing Systems

Jorge Arinez, Stephan Biller
Manufacturing Systems Research Lab
General Motors Research & Development Center
Warren, MI U.S.A. 48090
jorge.arinez@gm.com, stephan.biller@gm.com

Abstract

This white paper discusses the need for innovative technologies based on measurement and control to make manufacturing systems and equipment more energy efficient. Two objectives related to technology development are presented. The first is to obtain finer granularity in energy performance information from systems to improve current operations. Secondly, use such information along with lifecycle analysis to improve the energy efficiency of future designs for both systems and equipment.

Numerous studies have reported that industrial energy usage represents approximately 30% of the total U.S. annual energy consumption. Reducing the level of energy consumption serves many interests related to national security, the environment, and the economy. Energy saving technologies have already been developed which according to some accounts offer U.S. industry the ability to save 10% in present operations. However, to meet ambitious national energy reduction goals for industry, further technological innovations are needed.

To identify and develop the requirements for such technologies, we need to first understand the detailed nature of energy consumption in manufacturing systems. Clearly, the measurement of electricity and of other utilities exists and is well understood. The utility metering of large areas of industrial operations provides an overall indication of gross energy usage, however, details of energy utilization of individual pieces of equipment is not easily obtained and in many cases does not even exist. As costs and regulatory pressures mount to achieve ever increasing levels of efficiency, energy consumption information at a finer granularity will need to be probed to identify demand patterns. Given such knowledge, appropriate strategies and technologies may then be more effectively deployed to address energy reduction opportunities. Also, as the capability to measure detailed energy utilization grows, insight into sub-system interactions will lead to further efficiency improvements.

Broadly speaking, there are three basic ways to reduce energy consumption. The first and most immediate deals with real-time control. In simple cases, control consists of simply turning a device or process on or off. In more complex processes, advanced multivariable control algorithms may be employed. The second approach is to modify or change some fundamental parameter or constraint of a manufacturing process so that a greater efficiency is achieved beyond real-time control. This approach requires more time as it may involve detailed engineering analysis, optimization, and validation before a redesigned process is commissioned. The third way to reduce energy has the longest time horizon since it involves the design of new energy efficient equipment. This last approach offers the greatest opportunity for achieving large energy savings because all currently available advances in technology may be integrated into the design of new equipment. Depending on the manufacturing industry, this opportunity may only occur infrequently so when the occasion arises, effort must be made to incorporate all existing knowledge into the design of higher efficiency systems and equipment.

For all of these three general approaches, information obtained about the system's energy performance behavior through detailed measurement of sub-systems and individual equipment can yield improvements in energy efficiency. For each of these paths to energy reduction, there are corresponding technical challenges and barriers which need to be overcome. It is here where advances in measurement methods and standards are particularly critical as a basic data and information infrastructure is needed to enable the desired improvements in energy efficiency.

For example, given that there is already throughput, cost, and quality data being collected, how should real-time energy data be acquired and integrated to provide a meaningful metric of system performance for effective energy-related decisions to be made? This question spans multiple domains resulting in the need to make correct tradeoffs to achieve energy savings and meet production objectives. Furthermore, since there will be a greater amount of data required to execute real-time monitoring and control of energy, naturally there will be additional costs to be borne by manufacturers. In some scenarios, it is quite plausible that deploying new measurement devices may be cost prohibitive and therefore implicit methods to determine energy consumption will need to be devised. The specification and subsequent development of low-cost, energy-aware sensors and actuators will need to occur simultaneously to allow for such pervasive monitoring and energy control. Also, standards for the design and deployment of optimal sensor networks for such "smart" energy devices will need to be in place for integration with higher level energy management systems.

Another challenge is the lack of integrated data between energy management systems and lower level processes. As an example, with high-level energy reporting, detection in the degradation of energy performance of individual processes is obscured by the large amount of aggregation in energy data which occurs. Therefore, meaningful hierarchical organization and aggregation of energy data is necessary to identify and isolate faults, leaks, or other process parameter fluctuations which result in poor energy efficiency. Measurement and diagnostics of the "health" of equipment and processes is a vital aspect of an efficiently performing system. Processes can only perform efficiently if they are maintained in a state of continuous calibration where drifts in set-points are prevented.

In addition to improving current operations, consideration must also be given to the performance of future systems and equipment. For this, lifecycle analysis which uses historical data having the fine resolution described above must be communicated to system and equipment designers alike. This data will permit designers to develop systems which can be more easily adjusted to reduce peak energy requirements and provide overall gains in average consumption. Furthermore, designers will not only have a better knowledge of expected energy efficiency, but will be able to better model and design the system to achieve even greater savings. Hybrid simulations which not only model discrete quantities such as throughput, cost, and quality but also incorporate continuous energy consumption profiles will undoubtedly improve the design and validation of energy-efficient manufacturing lines.

In conclusion, to obtain transformative changes in the energy consumption of manufacturing systems will require advances in all of the three approaches described. The foundation of detailed energy performance information which is both reliable and accurate rests on a core infrastructure of standards and measurement methods.

Manufacturing and the Smart Grid

Today there is a growing emphasis on the environment and particularly on energy utilization. The main point being addressed here is the future of electrical power demand and the realization of a 'smart power grid.' As programs are being developed to address the makeup of a smart power grid, attention also needs to be placed on tools to assist in coping with changes in power consumption requirements when a smart grid poses a demand to change (lower) power usage. That is, the requirements to reduce ones draw on the grid to permit power to be allocated to a higher demand need.

One area that will potentially have to react to power demand changes is small- and mid-size manufacturing enterprises. Today, tools do not exit to aid a manufacturer in determining how to react to a power demand change. There are no smart tools to interface with the smart grid at the manufacturing shop level.

Some large companies are beginning to look at power consumption and are addressing it by monitoring the use of power at the equipment asset level. With this, it can be determined what assets consume what levels of power as they operate. In turn, it can then be determined which may need to be turned off to meet various demand needs. This method, however, is not necessarily the most efficient way to run an operation having to maintain a high level of asset utilization to maintain a profitable business. While it does provide a relative level of decision making capability, it does not carry the level of intelligence required to determine how to maximize asset utilization.

A better concept is to understand how various processes consume power during each segment of performing a task (e.g. a machining operation) to permit a change in the process to an alternate process plan. This approach will aid manufacturing engineers to develop process alternatives to produce product while maintaining a relative high utilization of plant resources. This methodology permits a company to optimize production to match power constraints.

This advanced type of decision capability does not exist today to permit "dynamic" production and process planning based upon power demands. To provide this capability, developments are required from various new enabling technologies. From technologies providing common data acquisition capabilities at the individual process level, to new applications and computing capabilities. The task being, the ability to match actual process steps to power usage and provide alternate process steps during low demand timeframes. If this is achieved, then various process recipes can be formed to meet varying power demands while maintaining sustainable production needs.

In the past this was not possible since data could not effectively be extracted from manufacturing equipment to make the necessary correlations to determine what steps consume what amount of power. Alternatively, to plan for executing certain manufacturing steps during low electrical demand intervals.

Recently a new standard has been developed, and is being further enhanced, to provide a common protocol and communication structure to acquire the necessary data to permit the linking of process steps to power usage. This standard is MTConnect[SM]. A royalty free open standard based upon Internet Protocol and XML language (refer to MTConnect.org web site for more information).

With the use of this standard, data can be collected or acquired by applications from discrete equipment, using standard networking technologies, to provide the necessary information to structure the above goal. This is the enabler to permit innovative technology developments that can be utilized in a myriad of ways to structure solutions to meet the future demands that will be placed on small- and mid-sized manufacturers by a 'smart power grid.'

Proposal 1:
Develop software tools and applications that can assist small- and mid-sized manufacturers in addressing power requirements requested by a smart grid.

Program Components:

1) Develop products and components that permit the adjustment of process requirements based upon energy demand loads.
2) Provide resources to permit enhancements to the MTConnect open standard and tools to address new data requirements.
3) Investigate new computing technologies and concepts that may be utilized for implementation.
4) Additional software development incorporating "cloud computing" through internet connections and MTConnect data capture that also includes a customer's power usage, rates, high/low demand time intervals and potential variability of dynamic electrical usage during manufacturing processes.

Proposal 2:
Develop and promulgate Energy Star criteria for "Industrial Machines" (a new category) for both U.S. machine tool builders and their customers. All benefits of the existing Energy Star Program would convey that currently exist. This effort would provide a competitive edge to manufacturers and users of U.S. machines while in parallel providing energy savings within the manufacturing sector.

Program Components:

1) Develop products, and components, that are themselves more energy efficient (Energy Star), and
2) Assist manufacturers and users in becoming more energy efficient with their own buildings and operations in preparation for "smart grid" connections.
3) "Industrial Machines" would become a separate and distinct category under the Energy Star Program coordinated with EPA and DOE.
4) Both the "Industrial Machine" manufacturer and the user of the "Industrial Machine" are tethered through a "smart grid" for measuring efficiency over an extended timeframe. Analysis via "cloud computing" will determine where and how additional efficiencies can be realized and improvements for greater energy savings.

Contact:
Paul Warndorf
VP-Technology
AMT – The Association For Manufacturing Technology
703-827-5291
pwarndorf@AMTonline.org

Dual Manufacturing:
Manufacturing Both Real and Virtual Products

Dr. Michael Grieves, NASA MSFC/University of Iowa

Introduction

Product Lifecycle Management (PLM) is redefining the use of information throughout the product lifecycle and specifically, as discussed here, in the manufacturing phase of the product's lifecycle[1]. Product manufacturers need to consider manufacturing two products: the physical products that they have always produced and the virtual product that is the information about the physical product. This virtual product can provide manufacturers with a new source of value.

Information Mirroring Model and Virtual Products

PLM depends on the conceptual idea of real and virtual products. Before the advent of computer systems that could handle the massive amounts of information about a product, the only practical way to have information about a product was to physically possess the product itself.

If a quality inspector wanted to check the dimensions on a batch of components, then the components were physically shipped to the inspector. (In many firms, inspection of the received product at the firm's site is still the primary quality control practice.) While blueprints were available on the "as-designed" component or product, "as-built" information on each instance of the component or product that was built from that design rarely, if ever, existed.

All products start out as virtual products. That is ideas and information about what the physical product should be. These virtual products are then realized in physical form through the manufacturing process. The manufacturing of products can be divided into three phases: making the first one, ramp-up, and making the rest.

"Making the first one" entailed getting a physical product that embodied the ideas of what the virtual product was required to accomplish. Ramp-up and production ("making the rest") relied on the premise that these products would be close enough to the first one so as to be functionally and physically equivalent. The accuracy of that premise varies widely even today, which is why expensive quality audit inspection processes are required of the actual product instances themselves.

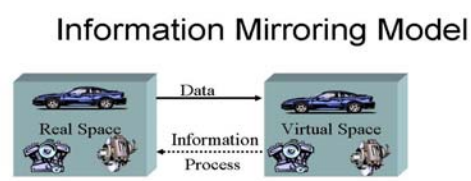

Figure 1

Progressive manufacturing processes now capture data about the product as it is being manufactured so as to create not only integrated product and process traceability, but a virtual product model as the physical product is being built. As inspection processes become more technologically sophisticated and automated, the ability to create robust virtual representations of individual physical components and products becomes not only possible but also necessary.

These virtual representations form one of the components of the PLM Information Mirroring Model (Figure 1) and are a main element to allow Product Specification Management (PSM) to exist and perform a critical role in enabling quality as part of PLM. Product Specification Management consists of three components: the physical inspection hardware (gauges, CMM, scanners, etc.) to collect data as product is manufactured, middleware to take and organize this station-based manufacturing data and build a cohesive virtual products, and an Manufacturing Execution System (MES) to serve as a repository for this "as-built" virtual product.

The Value of Virtual Products

There are a myriad number of uses that can be made of the virtual product created through PSM. In the manufacturing or build phase, the "as-built" virtual product is immediately available and can be transmitted to customers and other parties in the supply chain who need the information about the product to assure themselves that the product is actually being created to the required specifications.

Unlike the physical product itself, the virtual product can be sent over large geographic areas instantaneously and can be sent to multiple locations simultaneously. As described elsewhere[2], the new slogan of "transmit us the virtual product and we will then tell you whether or not to ship the physical product" may define a new paradigm in purchasing and manufacturing.

One automotive manufacturer has created a collaborative virtual space with its suppliers where the inspection of component parts at the supplier and later at the OEM is correlated down to the inspection point – though each may use different inspection methods and devices. The introduction of this collaborative model contributed to an 85% reduction in build issues in the subsequent model year as reported by the OEM.

In the create phase, the as-built virtual product can be used to validate the design of new, similar products. The data collected on actual results compared against specifications is invaluable in assessing manufacturing validity of new designs. By providing a feedback loop, the engineering / manufacturing divide can be bridged, reducing the slow iterative process of trial-and-error typically performed by manufacturing companies.[3]

For instance, while a specification and its associated tolerances may be manufacturable for the beginning of a production run, it may be that tool and die wear over a much larger run does not allow for those specifications to be met. Having the sequence of virtual products allows designers to understand either the requirement for different specifications or understand when new tool and/or die replacement is required.

At another automotive manufacturer, historical process capability information contained in the as-built virtual product of current and previous product models is being captured in the early design of new product models. This is in the form of dimensional tolerances that can realistically be expected to hold using similar manufacturing methods. In the absence of PSM technology, defining the proper tolerances in design for manufacturability (DfM) is a notoriously uncertain and difficult exercise, where the risk is that improperly assigned tolerances will lead to costly rework in design and tooling.

In the support phase, the issue of product liability often hinges on proving whether or not the individual product was manufactured to the required specifications. Without the ability to present data about the manufacture of a specific product, companies are at the mercy of plaintiff attorneys who raise doubt about the manufacturing process by asking "Isn't it possible that the bolts holding my client's seat were not tightened properly? Having the as-built virtual product, especially after the physical product may have been destroyed in an accident, gives the manufacturer protection against such an accusation.

Already, the US government has legislated detailed traceability at the level of individual product instances as a requirement on the F-35 JSF aircraft program, necessitating the implementation of PSM technology by the prime defense contractor and its suppliers. NASA has a one-hour informational demand in the event of an on-orbit anomaly for the Constellation project.

Conclusion

We have only manufactured physical products in the past, because we could not manage the amount of data that virtual products need. The exponential advances in computer technology are making virtual products feasible. Virtual products, i.e. the information about the product, have a myriad of uses, not only in the manufacturing phase, but also throughout the product lifecycle. Product Specification Management as part of Product Lifecycle Management defines the components necessary to capture and organize manufacturing data into virtual products. Manufacturers need to consider moving from single manufacturing to dual manufacturing: manufacturing physical and virtual products.

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[1] See Grieves, Product Lifecycle Management: Driving the Next Generation of Lean Thinking (McGraw-Hill, 2006)
[2] See Dr. Michael Grieves, *MES: Achieving Real Quality through Virtual Products*, 2008 Whitepaper
[3] See Dr. Michael Grieves, *Multiplying MES Value With PLM Integration,* 2007 Whitepaper

Manufacturing Simulation: The Need for Standard Methodologies, Models, and Data Interfaces

Charles McLean
Guest Researcher
Manufacturing Simulation and Modeling Group, NIST

Simulation technology can provide a highly effective means for evaluating the design of a new manufacturing system or proposed modifications to existing systems. This technology can be especially useful in supporting agility, sustainability, supply chain integration, as well as the development of new advanced processes. Manufacturing simulations are often used as measurement tools that predict the behavior and performance of systems that have not yet been implemented, or to determine theoretical capabilities of existing systems. Simulations are essentially experiments. As defined in Jerry Banks Handbook of Simulation, a simulation is: *"…the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operational characteristics of the real system that is represented. Simulation is an indispensable problem-solving methodology for the solution of many real-world problems. Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real systems. Both existing and conceptual systems can be modeled with simulation."*

Although the potential benefits of manufacturing simulations are significant, many problems still exist. For example, the development of individual simulations within industry is still often more of an art than a science. Simulation methodologies have not been standardized - the skills and experience of the simulation analyst may greatly affect the way a simulation that is developed, the type of model that is constructed, the time it takes to build the simulation, as well as the utility and correctness of the results. Another major problem, is the lack of standard models – with each new simulation study, models are often built from scratch, resulting in redundant development efforts and the possibility of introducing new modeling errors. Finally, the lack of standard data interfaces makes it costly and time-consuming to transfer data back and forth between other manufacturing information systems and simulations.

Key Drivers for Manufacturing Simulation R&D

Agility – Wikipedia defines agile manufacturing as a term applied to an organization that has created the processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality. Although historically discrete event simulations have been focused on addressing a number of issues relating to agility, e.g., system performance, throughput, and operating costs, simulation technology does not currently meet all needs in this area. Its biggest shortfall is in the time and cost associated with developing the simulations themselves. Simulations may take months to develop and are often not built because manufacturing managers are looking for immediate answers. Solutions are needed to accelerate the modeling and simulation development process, as well as to insure the technical correctness of the simulations themselves.

Sustainability - Simulation technology has been a significant tool for improving manufacturing operations in the past; but its focus has been on lowering costs, improving productivity and quality, and reducing time to market for new products. Sustainable manufacturing includes the integration of processes, decision-making and the environmental concerns of an active industrial system to achieve economic growth, without destroying precious resources or the environment. Sustainability applies to the entire life cycle of a product. It involves selection of materials, extraction of those materials, manufacture of component parts, assembly methods, retailing, product use, recycling, recovery, and disposal. Changes will need to occur if simulation is to be applied successfully to sustainability. Manufacturers will need to focus on issues that they have not been concerned with before. Since there has not been a demand for simulation technology with sustainability features, simulation software vendors and analysts have not typically addressed these issues in the past.

Supply Chain Integration – To achieve supply chain integration, multiple enterprises often need to work cooperatively to deliver end products. Some examples of the functional elements of a supply chain may include component part and raw material suppliers, transportation networks, distributors, warehouses, final assembly plants, and retailers. Typically, some elements of a supply chain will cross enterprise boundaries. Simulation analysts building supply chain models may need to interact with peer analysts in other enterprises that use different simulators for their enterprises. Complete internal information on each supply chain element may not be available to the analyst due to proprietary issues. Major research issues that need to be addressed include the development of distributed supply chain simulations using different simulators as well as the exchange of information between these simulations, e.g., standard message formats and access to shared databases. Data specifications are needed to identify the types of information that will need to be exchanged between different suppliers models, manufacturing applications, and databases. Examples of data that needs to be shared includes orders; schedules; tooling, raw material, work-in-process (WIP), finished part inventory and tracking data; production capabilities and capacities; resource status and usage; reject and rework data.

Other research areas include the development of simulation integration infrastructures using Web services technology that will allow supply chain partners to connect simulations of their facilities over the Internet. To address production requirements, simulations will need to include technical solutions for modeling manufacturing supply chains at multiple levels. Web-based solutions could enable the integration of multiple simulations at the supply-chain, enterprise, plant, and shop-floor levels. Off-the-shelf solutions do not exist today.

Advanced Manufacturing Processes – Some of the issues associated with the development and implementation of new, advanced manufacturing processes includes process validation, process capability analysis, tolerance analysis, ergonomic analysis, and tool design. Simulations can support these activities through: the modeling of systems, the execution of manufacturing plans, programs; the use of statistical process control techniques to determine whether processes can be kept in control range; modeling the effects of tolerance stack up on overall tolerance budget for a product or machine setup configuration to determine the probability that an instance of the product will meet specifications; evaluation of ergonomic aspects of worker tasks for efficiency of operation, theoretical production rate, risk of injury, rest requirements; and the development of tool management plans, definition of standard tool sets, prediction of tool wear, etc. Although special purpose simulation tools have been commercially developed to support each of these areas, standard data interfaces that would enable the exchange of data between these tools is very limited.

Need for the Development of New Simulation Standards

Need for Standard Methodologies - Simulation case studies are conducted to analyze and improve the efficiency and effectiveness of manufacturing organizations, systems, and processes. A study essentially represents a methodology for solving specific problems and getting answers to specific questions. Studies often model some aspect of current operations and validate the effect of some hypothetical change(s) to those operations. The performance of current and proposed systems are evaluated according to some set of metrics. Simulation textbooks typically recommend that a ten to twelve step process be followed in a simulation study. The recommended approach usually involves the following steps: (1) problem formulation, (2) setting of objectives and overall project plan, (3) model conceptualization, (4) data collection, (5) model translation into computerized format, (6) code verification, (7) model validation, (8) design of experiments to be run, (9) production runs and analysis, (10) documentation and reporting, and (11) implementation. Unfortunately, this approach often leaves considerable work and possibly too much creative responsibility to the simulation analyst.

Each new simulation case study performed today probably repeats at least some work previously done by others. Case studies typically contain proprietary information that private companies do not want to share. For this reason, it is unlikely that most case studies will ever be seen outside of the company that commissioned them. How can the duplication of work be minimized? The development of standard templates for different types of case studies would be a step in the right direction. More work could be done to create case study templates that are generic but more problem-domain specific, e.g., scheduling, layout, and material handling.

Individual case studies should be able to be used as modular building blocks and templates to solve more complex manufacturing problems. Ideally, case study templates should be "atomic," i.e., unique, indivisible, and non-overlapping. A rigorous analysis should be used to ensure that each case study forms a clean, basic building block. The analysis should aim to assign any specific objective or question type to only one type of case study. A major reason for this rule is to avoid the infinite proliferation of custom-defined case studies. Repositories would need to be established for the case study templates so that they could be readily accessed by simulation analysts and software developers. Resources in the academic, research, and standards communities could be applied to this problem, thus avoiding the proprietary information content issues.

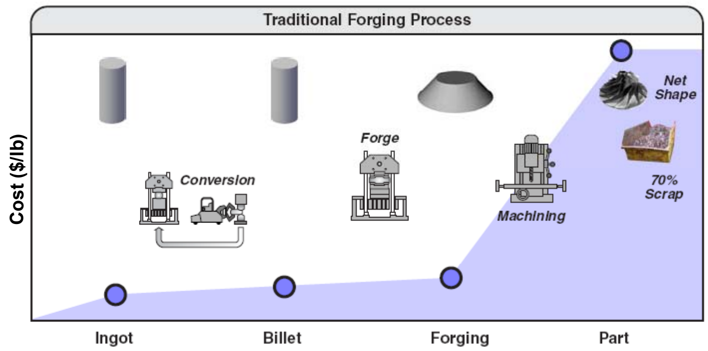
Need for Standard Models - Neutral model formats would help enlarge the market for simulation models and make their development a more viable business enterprise. Model libraries could be marketed as stand-alone products or distributed as shareware. Standard formats for models would make it possible for simulation developers to sell model libraries much the same way clip art libraries are sold for graphics software packages today. Simulation model libraries could be expected to increase the value of manufacturing simulators for industrial users much the same way graphics libraries increase the value of photo processing, paint, and graphics illustration software packages to their users.

Need for Standard Data Interfaces - The development of neutral, vendor-independent data formats for storing simulation data could greatly improve the accessibility of simulation technology to industry by enabling the development of reusable models. Such neutral, simulation-model formats would enable the development of reusable models and reference data by individual companies, simulation vendors, equipment and resource manufacturers, consultants, and service providers. Reference data sets to support sustainability could also be developed to provide information on energy consumption, alternative processes and materials, pollution data, improved equipment capabilities, worker task analysis, job satisfaction evaluation criteria, material recycling and recovery opportunities, community impact, mitigation strategies, etc. Standard message formats are needed to facilitate the exchange of information between simulations built by different organizations within supply chains.

Challenges in Net-Shape Manufacturing of Metallic Parts

WT Carter, JS Marte, SR Hayashi, SV Thamboo
GE Global Research Center, Niskayuna NY 12309
carter@ge.com

Manufacturing of metallic parts can be accomplished by a large variety of processes including casting, forging, machining, powder processing, welding and countless others. Intrinsic to all of these processes is the desire to achieve a final in-service geometry – with requisite material properties – at the lowest possible cost. A typical cost flow analysis shows that cost quickly compounds late in the processing sequence. For example, in the processing and machining of a forged part shown in the figure to the right, the machining step (often viewed as an inexpensive process) actually adds significant cost because of the value of the metal removed and scrapped. If upstream processes to achieve *net- or near-net shapes* were fully developed, machining losses would be reduced to an insignificant level and the overall part cost would be far lower. However, ***achieving net shape early in processing is an elusive goal.***



The benefits of net shape processing to the US manufacturing infrastructure is clear in the reduction of wasted material and machining costs. Additional benefits include reductions in the energy and greenhouse gas emissions associated with production, transportation, and recycling of wasted metal. Such reductions would impact material sustainability and availability for high-tech manufacturing, and provide a competitive advantage for US manufacturers. Modern net-shape processes include the traditional (e.g., investment casting) as well as emerging (e.g., laser additive methods, isothermal forging, powder metallurgy) technologies. In addition to improved material utilization, many of these processes provide an opportunity to introduce technological and practical advances, such as location-specific properties, lean manufacturing cycles, and inventory reduction. However, the full benefits of the processes have not been exploited because of economical and technical challenges. Cost is a key driver, and cost is driven by process rate, yield, raw material cost, capital cost, repeatability and flexibility. Many of the technical challenges are similar to those faced by the established processes: microstructural defects, shape retention, equipment capabilities, etc.

Net-Shape Deformation Processes

It may seem obvious from the plot above that achieving near-net shape from a forging can reduce the machining cost. This is true, but forging press capacity, die material strength, and workpiece plasticity impose practical limitations that have not been overcome. Improvements in ingot and billet material that enable net shape forging can have a large impact. Superplastic forming, for example, has been commercialized for a few sheet metal applications, but shows promise for bulk deformation as well. Required developments include thermomechanical processing for producing superplastic billets, alloy design methodologies for meeting property requirements for both service and processing, (alloy developments to date have concentrated on in-service material property requirements, ignoring the processing limitations), and the development of advanced presses equipped with controls to forge to net-shape.

Material Additive Processes

Material additive processes include laser-net-shape manufacturing, direct metal laser sintering, plasma transferred arc and electron-beam free form fabrication. They typically require expensive metal powder or wire as a raw material. Despite the high cost of raw material, these processes find niches in manufacturing where local additions of expensive metal is more economical than removing a large amount of less expensive metal from an over-sized workpiece. Where small numbers of parts are required, the additive processes obviate the need for expensive tooling, thus becoming economically favorable. Tailoring properties by tailoring chemical composition to the local requirements such as corrosion resistance, wear resistance, chemical resistance and hydrophobicity seems to be an obvious benefit of these processes, but this advantage has not been largely exploited. The largest obstacle these processes face is the presence of microstructural defects (e.g., voids, impurities, or inclusions) in the final product; such defects can lead to catastrophic failure. Developments in process monitoring and control with in situ defect detection and remediation could reduce or eliminate the cracks, inclusions, and pores between deposit layers.

Joining

The advent of high brightness lasers makes it possible to weld thick gauge materials commonly seen in numerous industries including windmill towers, locomotives, and pipe. These high brightness lasers enable the welding of materials that are up to 1 inch thick in a single pass. This is significant. Utilizing today's technology (e.g., metal inert gas or submerged arc welding) requires a “weld prep” where metal is removed and scrapped, then *replaced* with weld metal filler wire. The ability to weld 1-inch plates in a single pass can lead to a 90% reduction in both energy consumed and CO_2 emissions during the manufacturing process. For the heavy industrial manufacturing sector in the United States, this amounts to a reduction of $2.98x10^9$ kWh/yr. Combined with technologies that reduce the forging envelope, research in advanced joining will provide additional opportunity to introduce net shape manufacturing into the supply chain.

Advanced Machining

Several new machining techniques that combine electrical, chemical and mechanical removal of material are emerging with the goal of increased throughput. These techniques apply lower mechanical loads, leading to lower capital equipment costs due to reduced machine stiffness requirements. They enable cost-effective machining of high-performance materials that prove difficult or impossible to machine conventionally. Environmental stewardship adds a burden to these new technologies, requiring process developments.

In line monitoring of the output of high-throughput machining centers is required to ensure that the product consistently meets geometric tolerances. However, conventional gauging and tooling is expensive and inflexible. High-speed, general-purpose, non-contact measuring systems could detect tool wear or alignment issues, allowing corrective actions to center products within customer tolerances.

A review of the balance sheet of a typical machining center indicates that approximately 10% of income results from the sale of machining chips and scrap metal. As this amount represents the typical net income of such a center, the chips and scrap must be viewed as a *product* rather than waste. High speed detection and sorting of chips by alloy composition can add significant value. Reclamation of machining waste in electrochemical machining processes should be addressed.

Recommendations

While there has been impressive fundamental work in some of the above areas to develop new technologies, they have not been widely implemented. In some cases this is because of high initial investment. In other cases, new design practices to take advantage of new materials have not been established. The key areas in R&D needed to overcome the challenges of net shape manufacturing should include:

- Development of new manufacturing technologies for net shape manufacturing
- Enhancing current net shape manufacturing technologies
- Modeling & simulation of net shape manufacturing processes
- Developing design practices capable of taking advantage of the new technologies
- Devising approaches for process control that incorporate in-line monitoring and adaptive control

Third Wave Systems, Inc.

The Future of Advanced Alloy Manufacturing: Material Modeling

Advanced alloy development is an active area of research with pervasive impact on the United States' manufacturing industry; indeed airframe, jet engine, power generation, medical device, defense, and automotive companies all stand to benefit from such research. We need to avoid time-consuming traditional methods of development and access state-of-the-art micromechanical modeling techniques that accelerate the development of these alloys and sustain our country's global competitiveness. Unfortunately, a disconnect currently exists between alloy developers and the manufacturing base of industries that want to machine components utilizing new alloys. Time-to-market advantages are being lost while our manufacturing base struggles with machinability issues that accompany new, unfamiliar alloys. Additionally, new alloys are inhibited from broad-based dissemination due to prohibitive manufacturing costs.

Computational alloy design is an emerging approach to new alloy development that relies on mechanistic and predictive material models. By working with the end-user of an alloy, the final microstructure is optimized for the best combination of relevant properties. During the computational alloy design process, structure-property models dictate optimal microstructure to achieve the desired properties; in turn, process-structure models dictate optimal processing to achieve the targeted microstructure. In the last decade, such physics-based material modeling has proven to be an effective method for reducing new process costs and accelerating process implementation.

We now need to fill the void of structure-property models relevant to machinability using a combination of computational alloy design expertise and machining simulation leadership. Current computational performance levels often impede rapid tooling and process development, but these tools can be expanded and leveraged using advanced machining simulations to incorporate both alloy performance and manufacturability into a concurrent engineering framework for high performance alloys. By focusing on relevant microstructural features and their impact on properties that drive machinability, the United States can leverage the same process-structure models utilized in alloy design to develop an annealing cycle that achieves targeted microstructures. For example, it may be possible to design a titanium alloy annealing cycle that accesses a morphology of coarse alpha particles otherwise undesirable for material toughness, while being compatible with a subsequent final heat treatment to restore the properties of the final product.

It is time for the manufacturing community to adopt integrated multiscale physics-based predictive modeling for the development of machinable advanced alloys and corresponding component machining processes. By incorporating micromechanical constitutive models from alloy development models into physics-based machining models, manufacturers will gain detailed microstructural information about new machined components. In addition, outputs from physics-based machining models will also serve as a machinability feedback loop during alloy development, enabling developers to improve alloy machinability in the development stage while maintaining high performance design properties.

Technology is the wave of the future, and an industry driver for the United States' emergence as the leader in developing advanced alloys both affordably and time-efficiently. The task is complex – finite element modeling must account for geometric, tooling, speed, feed, and other extrinsic machinability factors using validated experimental techniques – but not unfeasible. The reward will be simulation accuracy that provides insights to intrinsic material properties that influence machinability. The end result is a substantially more productive, more competitive U.S. machining sector, generating high profits and providing products to market much faster – particularly components made from advanced alloys. It's time to start machining smarter.

21st Century Methods for Composite Processing

Thomas Rose: Advanced Processing Technology, Norman OK, 73071, Ph405-360-4848

Energy is a critical to the economy of the US. Composite materials address many of the energy issues both to produce energy in products such as windmills and to save energy in products such as car bodies and aircraft. There is also a need to update infrastructure to retain and regain jobs in the USA.

By 2010, the global market for Carbon Fiber Reinforced Plastic (CFRP) composite materials is predicted to be worth $13.6 billion, representing a huge increase of 37% over 20061. CFRP also has a role as a replacement for metals in infrastructure. Corrosion of metallic structures has a significant impact on the U.S. economy. In a congressional study, the total economic impact of corrosion and corrosion control applications was estimated to be $276 billion annually, or 3.1 percent of the U.S. gross domestic product (GDP). 2 Estimates for the DoD alone are between 10-20 Billion.

While the use of composites has grown, many of the manufacturing and repair processes have remained stagnant. There is a large and growing need to update the underlying technology to take advantage of new tools developed over the past forty years. Hundreds of millions of dollars are wasted each year using specifications and practices that had their genesis in the 1950's and 1960's.

The need to update these specifications and practices has a significant relevance to retaining jobs and advancing both defense and commercial industry within the United States.

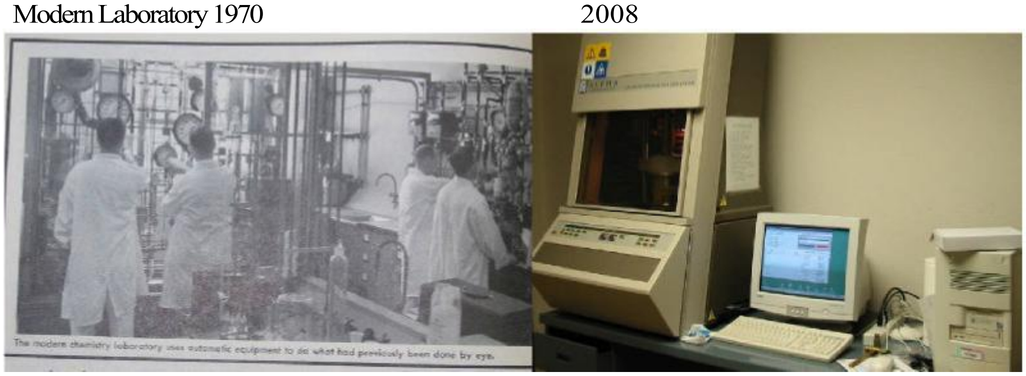
Background and Approach: Current specifications for composite materials were developed before it was possible to measure material properties during manufacture so the approach was to use the same material and process them the same way every time. The integrity of this practice relies on a “no change” policy.

Stated another way, any change in the process is unacceptable because its effect on the performance of the material is unknown. The objective of this white paper is to increase the visibility of properties critical to performance during the process and thus enable far greater range of acceptability. This enables many more opportunities for cost reduction and performance improvement.

Fundamental to all process improvement is the ability to link material properties to performance and then optimize around those properties. The improvements in computers, cure models, communication, instruments and sensors combine to make it possible to measure and link material properties to process actions with far greater accuracy that was available in the past.

The benefits range from salvaging a bicycle part that might otherwise be scrapped, to the ability to build a complex bridge or sophisticated weapon that would be impossible using the legacy technology.

Modern Laboratory 1970 2008



Challenge: The barriers to change are high. Success requires new infrastructure. There is no requirement for change to infrastructure without a specified requirement. The 'catch 22' is that specifications cannot change without data and without a change to the infrastructure one cannot gather the data.

By leveraging the knowledge gained from past processing science programs4 and substitution methodology projects5 and by using new instruments, computers and data management systems, an infrastructure can now be developed with the final goal of new specifications for manufacturing.

Goals: The near term goal is to adapt instruments, equipment and software to create processing alternatives. During this phase the goal is more efficient and accurate methods evaluate materials, address production problems and improve manufacturing methods within the limits of existing specifications.

The basic components to support the MSM approach have been installed and multiple milestones have been achieved.

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- Instruments to measure state of prepreg during cure with linkage to controls.
- Cure models that can be validated using low cost in process methods
- Microwire sensors to determine temperatures deep within a laminate
- Linkage of models and microwires for cure modeling
- Remote link of process equipment to lab instruments
- Real time and post process determination of visco-elastic state

These technologies are ready to be tested and evaluated in manufacturing and, if properly supported, will provide durable jobs based on a domestic infrastructure. Many of these improvements can be targeted to applications such as bridges, and buildings whose jobs cannot be relocated.

This will require a multiyear effort within the framework of a collaborative effort with industry, academia, and government. This work is still developmental and is expected to include failures and successes as the balance between sophistication and shop friendliness evolves. In the end such an approach will inevitably lead to major cost savings and performance improvements.

AvPro has worked in collaboration with large (GKN, Spirit Aerosystems, Rockwell Automation Roper), small (Thermal Solutions, Helicomb, First Wave) universities (Wichita State, Oklahoma University, UCLA) and others to demonstrate proof of concept and lay the foundation. Much work needs to be done that can only be achieved with additional resources and beyond the scope of AvPro and much of which must ultimately reside in the public domain and therefore has limited potential for attracting private capital.

Much of AvPro's work has been within the aerospace community: thus emphasis on the catch 22 regarding specifications. However a similar catch 22 exists in the commercial world that is less defined and therefore a greater challenge. If it has not been done before and does not have an immediate ROI tied to a tangible product, venture money is extremely difficult to obtain. Thus truly innovative ideas that derive their utility from an existing infrastructure will not be funded until the infrastructure is in place but the infrastructure requires products, the development of which venture money will not fund.

In summary: there is a significant opportunity to lead in many areas of composite processing if the tools to support it are developed. Personnel directly responsible for materials and processes from both the public and private sector support the concept. Funding of a team with the proper vision and capability with resources to move from proof of concept done "below the radar" to a program large enough to instantiate change has not been available.

Many of the key drivers for this technology are the establishment of (a.) new methods based on (b.) new instruments that require (c.) data to determine repeatability, reproducibility of results and (d.) methods and standards to validate and substantiate the accuracy and precision of the results.

Product Tolerance Representation: Critical Requirements for Product/Process Interoperability

Curtis W. Brown, Engineer Principal Mechanical, NNSA's Kansas City Plant[1] and Daniel A. Campbell, Software Director, MetroSage, LLC

The "perfectly nominal" part is an ideal never fully achieved in manufacturing; however industry can fabricate parts that fit and function when acceptable limits from tolerances are introduced. Therefore a critical responsibility of a designer is to define product acceptability by augmenting the nominal geometric shape with the appropriate set of tolerances. Within the past 60 years, we have seen the refinement and standardization of tolerance representation which, when implemented properly, control the location, orientation, form, and/or size of part features in a complete and unambiguous manner.

Statement of the Problem: Current *electronic* product definition systems (i.e., CAD Systems) represent completely and unambiguously *only a segment* of the product's design. Product tolerance presentations are generally of the form of mere textual annotations, devoid of any meaningful association to the product geometry. This gravely limits the designer's ability to efficiently create and communicate complete and unambiguous tolerance information, and it cripples downstream applications that depend on such information.

What is Needed: A full semantic representation of 3-D geometric dimensioning and tolerancing (GD&T), within or tightly coupled to the product definition system.

Meeting the stated need in an adequate manner will require software capable of:

- Augmenting a solid shape with tolerance definitions
- Implementing the notion of tolerance features (collections of one or more topological faces)
- Representing tolerances semantically (not just as annotations)
    - Dimensional / coordinate tolerances
    - Geometric tolerances
    - Specifications (e.g., thread specifications.)
    - General property attributes (e.g., notes, markings, cosmetics)
- Designating functionally important tolerance features as functional datum features
- Building datum reference frames (DRFs) from datum features
- Associating DRFs to appropriate tolerances
- Assigning tolerances to appropriate tolerance features
- Recognizing tolerance features automatically and interactively
- Inferring correct tolerances automatically
    - Per ANSI Y14.5
    - Per company standards
- Checking, validating, and scoring a piece-part's functional tolerance definition
    - Are all geometric faces assigned to tolerance features?
    - Are all tolerance features properly constrained for location, orientation, size and form?
    - Are there any unused DRFs?
- Publishing application programmers' interface (API) suite
    - Extending tolerance analysis
    - Supporting downstream applications (e.g., inspection)
- Exchanging tolerance definition to other product definition systems

[1] The Kansas City Plant is operated and managed by Honeywell Federal Manufacturing & Technologies, LLC, for the NNSA

The Key Driver: Efficient and Economic Manufacturing

Tolerancing is an important aspect of design, plus the cost of correcting design errors during the design process is relatively low. Intelligent automated tolerancing capabilities and, in particular, the ability to independently check that a part's tolerance definition is correct, complete and unambiguous, will ensure that tolerance errors are caught early in the product development cycle.

Having validated tolerance information as an integral part of product definition means that, with suitable interoperability, the same validated information can be used in downstream applications, such as measurement process planning, measurement results analysis, assembly analysis, CMM part program generation, etc.

A Case in Point: Intelligent, Automated, Economically Optimized Inspection Process Planning

An important aspect of measurement planning is to ensure that the measurement devices and procedures to be employed are adequate for the precision required in the ensuing measurements. Another is to ensure that the measurements are carried out in an economically efficient manner, making optimal use of the measurement resources available. In inspection operations the precision of the measurements bears heavily on accept/reject decisions and can play a critical role in the risks of Type I and Type II errors, each of which has its own attendant economic consequences. Recent years have seen noteworthy advances in the theory of risk and cost analysis. National and international standards have addressed these concepts as well. Moreover, new software products now offer well validated estimates of measurement uncertainties *via* science-based modeling and simulation. Thus the essential theory and many component technologies exist for the implementation of an intelligent automated inspection process planning system, a software tool for use by the manufacturing community to enable the automated production of design-based measurement strategies of *known reliability* and *high economic efficiency.* Manufacturers using such a tool would find that they (1) could dramatically speed the production of measurement strategies for new or existing parts; (2) would know the reliability of these strategies; and (3) would know (based on their own assessment of cost functions for measurement, the costs of accepting a defective component or rejecting a good one) the economic consequences of each alternative strategy. Such capabilities offer the prospect of significant advances in profitability and product reliability.

With all that said, the problem stated at the outset of this document remains. Under current conditions, the potential user of such a system would not have ready access from the design system to validated tolerance information tightly linked to the part geometry. This presents an obstacle to what could otherwise provide a significant advance in manufacturing.

"Yeah we've got a tolerance problem alright, it's that we do not have a correct, tested, complete & unambiguous tolerance representation in our CAD systems and therefore we cannot use it for downstream applications and accurately exchange it"

Information models for machining interoperability, optimization, and simulation

Martin Hardwick
Professor and Acting Head of Computer Science, RPI
President STEP Tools, Inc.

Today, Computerized Numerically Controlled (CNC) machines are programmed using Computer Aided Manufacturing (CAM) systems that receive their input from Computer Aided Design (CAD) systems. The CAD systems are used to define the nominal geometry and required final dimensions and tolerances of a part. The CAM systems are used to define processes that will make the part by adding material to, or more commonly removing material from, a workpiece.

The input to a CAM system is a drawing or its equivalent and the output is a set of G-codes (Gerber plotter codes) that tell a machine tool how to move its components in a sequence. If the machine is setup correctly then executing these codes will reveal the part. The antiquated G-code language is now being replaced with a modern associative language that makes CNC programming more visual and easier to control. It builds on the STEP language that is implemented by nearly every CAD system. FANUC, the leading vendor of CNC controls, recently demonstrated a hybrid control that machines a part from a STEP-NC description. The figure below shows the data that was machined.

STEP Tools and an industry team of aerospace and heavy equipment manufacturers are testing STEP-NC and extending its capabilities to enable cooperative process planning and simulation by teams of suppliers. The extensions include:

- Definitions to speed up or slow down a program in response to changes in the production schedule. The aerospace industry has estimated that the average time for a machining job can be reduced by 15% or more if the process can be fine tuned in this way.

- Definitions to enable networked simulation so that a contractor can ask a team of suppliers to plan and simulate the manufacture of a part on multiple machines, at multiple locations and in multiple stages.

- Definitions to allow changes to the tooling so that an operator can make adjustments to a program received from a supplier without having to ask a CAM programmer to make a complete new program from the original drawing.

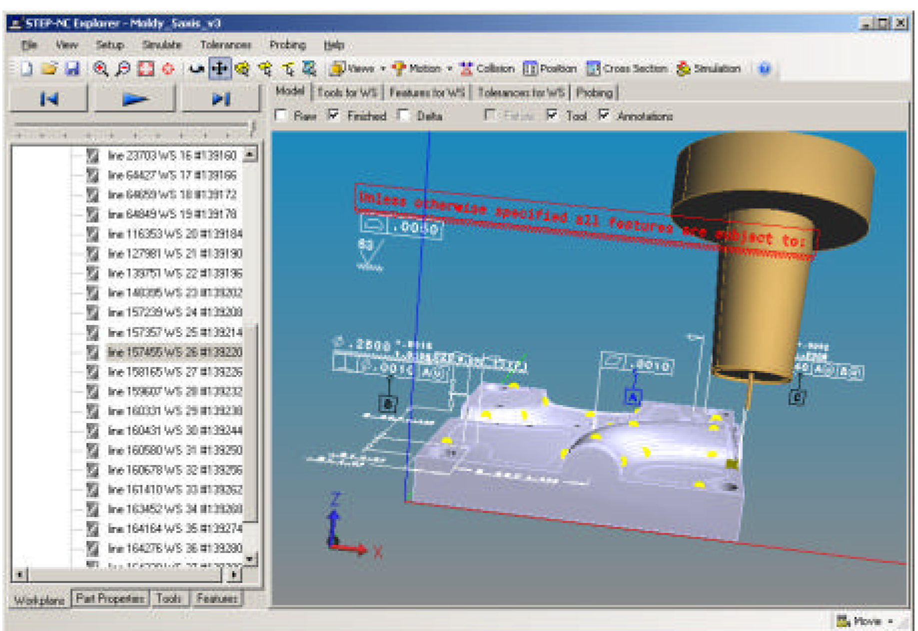
- Definitions to enable energy consumption estimates so that an enterprise can minimize the energy required to make a part by selecting the most appropriate machines and tooling.

- Definitions to adjust the machining programs using the results of measurements so that the form of a part can be adjusted to meet the current dimensions of a large assembly.

The mathematics required for these capabilities is mostly defined in the literature. The STEP-Manufacturing team is assembling an infrastructure that allows these definitions to be harvested in an open, shared framework defined by standards.

A new modeling method, called a Usage Guide, is being developed to add onto the STEP standards for the new semantics. The first Usage Guide showed how gears can be represented as AP-214 data. STEP-Manufacturing is developing a Usage Guide to describe the kinematics of machine tools in AP-214. Concepts first developed for ontologies are being used to enable **Dynamic Usage Guides** that can be customized to the requirements of specific machines and operations. Examples include the operations specific to a particular CAM system, and the program cycles specific to a particular machine tool.

The new STEP-NC programs are a shared resource that can be stored in appropriate media. The new programs can be edited and linked using software tools such as the STEP-NC Explorer illustrated below. Simulators are used to check the consistency of the programs. Engineers like to solve technical challenges but do not like to waste time because of antiquated methods such as G-codes. By making CNC programming more accessible, STEP-NC allows more innovative products to be developed more quickly. The definitions described here add new functionality to the standard so that the new products can be made faster and more cost effectively.



STEP-NC Part machined by Fanuc at Boeing Renton Plant on 7.14.2009.

White paper submitted to the NIST Workshop, November 3, 4, 2009

Personalized Production Paradigm

Y. Koren and W. Wang
The University of Michigan

How can we sustain a strong auto industry in the US?
How can we create new Small Business industries?
How can we create new manufacturing jobs?

Our proposed personalized production of automobile interiors will boost the US economy, and create new jobs and new industries. Instead of compromising on an interior design offered by the auto manufacturer, buyers will be able to design their new car interiors to meet their needs: Starting from an open interior space and filling it with available modules.

Automobile interior modules may include, computer stations, storage boxes, microwaves, refrigerators, beds, dog baskets, folding tables, clothing racks, and portable-potties for kids, etc. We are proposing an open-architecture structure for all these mechanical components, parallel to the i-Phone and PC electro-type open architecture software.

When this approach is adopted by the auto industry and mechanical-electrical open-architecture standards are established, dozens of small new companies will start to produce special modules (such as dog baskets and storage cabinets), which will evolve to several new industries. In addition to trading used cars, people will trade used modules as their needs change and they want to update and remodel their existing cars. Because this personalized production business model is beneficiary to both the manufacturers (that are being paid before the product is built) and to the customers (who are getting exactly the product that they need), and because it will generate new industries that produce innovative modules, it could be a giant booster to the US economy.

The main engineering research challenges are

1. Creating a new-generation of CAD based systems by which buyers, who are not necessarily engineers, could easily design their car interiors; it will apply control feedback principles, which will aid buyers to converge to arrive at their desired products.
2. Creating a new-generation of assembly systems that will be able to handle thousands of options, and still produce cars at mass-production cost.

The main practical challenges are defining the regulations and standards for mechanical interfaces that will guarantee safety, as well as defining the standards for electrical and information interfaces. NIST should take a leading role and work with General Motors, Ford and Toyota on establishing these standards.

Ushering in the Next Generation of Factory Robotics & Automation

Leandro G. Barajas, Ph.D.
Manufacturing Systems Research Laboratory, General Motors R&D Center, Warren, MI 48090
Andrea L. Thomaz, Ph.D.
School of Interactive Computing, Georgia Institute of Technology, Atlanta, GA 30332
Henrik I. Christensen, Ph.D.
College of Computing, Georgia Institute of Technology, Atlanta, GA 30332

The manufacturing capability and sustainability of the U.S. industry has been losing ground to its Asian and European competitors for the last few decades. For example, Japanese and German companies currently dominate the market of industrial Robotics and Automation (R&A) solutions with the support of low price Chinese manufacturers. Given the high labor cost in North American markets, the only viable option for U.S. industries to compete with a global market is via state-of-the-art R&A. Furthermore, most capital-intensive and wealth producing industries in the U.S. neither have the technical expertise nor the manufacturing capability to survive without cost effective R&A, which places these industries in a precarious state of vulnerability to disruptive technologies that may redefine the value stream map of their respective businesses.

The unfortunate reality is that the domestic production of consumer products using conventional processes could soon cease to exist based on a 30-year track record of global outsourcing pressure toward regions with low labor and investment costs. The transformational development and establishment of next generation manufacturing assembly processes using the latest in dexterous and intelligent robotics and lean production technologies will provide the necessary competitive edge for a variety of affordable products for the future. As a result, jobs will be retained as some will shift from line work to technical support and operation of the robotic systems.

The structured environment existent in current production facilities that enables robots to perform their tasks actually limits flexibility and drives a significant cost penalty for using robots. There has been some progress in enabling robots to operate in manufacturing operations with less structure, but robot capability in this area is very limited. This “robot capability gap” persists and limits the range of applications and business conditions under which robotics provide a feasible commercial alternative to other means of implementing manufacturing processes. This gap is especially evident in the automobile industry when examining the final assembly process.

From an end user perspective, we believe that a new generation of assembly automation can be anticipated to significantly reduce the reliance on fixturing, mechanized structuring, and conventional sense-plan-act programming. This capability would enable assembly automation with a set of little or no more infrastructure requirements than a completely manual process would. These new assembly processes will exploit the existence of a flexible robot perception system as an integral component of a three-part strategy that includes: 1) highly flexible robots/end effectors, 2) flexible perception, and 3) safe integration/harmony with people, which are also performing tasks in the assembly process. The cognitive component of the perception system would facilitate the “assignment” of the automation to a set of assembly tasks and/or assistance to others performing a task not yet appropriate for automation. This capability will also enable the rapid “reassignment” of the automation to other tasks as required by production mix and business needs. Many U.S. manufacturing domains stand to benefit from the flexibility and productivity that this form of dynamic automation brings to the assembly process. Multi-purpose robots that can safely collaborate with human workers will elevate the capabilities of existing assembly workers in the pursuit of providing quality products to end-users.

A key factor in creation and adoption of the next generation manufacturing technologies is the development of flexible perception and human-like control technologies. In addition, by taking a leadership role in the development and adoption of such emerging technologies, we could ensure that the jobs created in this new area stay in the U.S. These jobs can only be created and retained if a technological edge can be found that overcomes the attraction to low-cost labor regions. Through the pervasive use of intelligent R&A that can be as flexible and as easily trained as people, related industry jobs could also be moved from offshore to the U.S. as a direct result of this new technical capability.

Our goal is to see revolutionary advancements in dexterous robotics leveraged in a new energy efficient automation environment that combines the best possible mix of human and machine capabilities. These next generation robots include "safe robot" technologies that allow the seamless integration of people and dexterous robots in one lean process. The key factor for the success of this approach is that the new systems leverage the infrastructure and flexible material processes that traditional manual systems use rather than expensive and traditionally inefficient automation methods. This substitution enables a substantial reduction in R&A support investment that can normally be up to 10 times the cost of the robot themselves.

From a scientific point of view, this endeavor encompasses a wide range of disciplines. Even when current commoditized hardware capabilities are almost at the level required to enable us to cross the capability gap, the actual integrated control and communications software systems are still lagging due to the heavy burden of current legacy systems. The historical paradigm for controlling R&A systems relies upon the system designer being able to specify a priori every requirement and possible condition of the system. This approach leaves no room for changing conditions, adaptability, plasticity, and in general, learning.

One of the main hindrances that is currently preventing the evolution of the next generation R&A is the lack of standards of performance and test methods. Every R&A manufacturer attempts to keep their customer base captive by having closed and mostly incompatible systems. Most of the major specifications of these systems are given in terms of mechanical or electrical characteristics rather than in terms of overall system performance. NIST could play a vital role in advent of the new wave of R&A technologies by facilitating the dialog among interested parties and establishing both system standards and evaluation metrics in order to be able to track the level of capability improvement of such systems. Such specifications should not only encompass hardware and software metrology targets, but also high-level system qualitative and quantitative capability measurements for standardized processes. In a way, this will enable an R&A revolution equivalent to the one observed on the computer industry in the mid 1980's. Effects of this achievement will be reflected deep into the fabric of industry and ultimately into the entire society; but in this case instead of putting a computer in every home or pocket, it will enable the pervasive use of functional R&A in all areas of our daily lives, from the factory plant floor to even your kitchen floor.

We predicate that there is a unique opportunity to make progress in this arena by harnessing collaborations between industry and academia. Our existing collaboration between Georgia Tech and General Motors is one such good example. In our collaborative efforts to bring cutting-edge R&A technology from the labs to the factory floor, we are forced to reconcile some of the real issues involved with integrating flexible R&A with existing manufacturing processes and to focus on technologies that deliver real value added to the end customer.

Key Barriers to Rampant Random Bin Picking Retrofit Deployment

Dennis Murphey dmurphey@braintech.com
Braintech Government & Defense Inc. McLean, VA

With an estimated 1,000,000 robots deployed by the end of 2010 the increasing requirement for Advanced Sensor Retrofits to deployed Robotic Workstations is expected to continue to increase. Retrofit solutions have always made good sense for complex substantial installations for discrete and continuous process manufacturing. The barriers however have remained the same throughout the years: controller interface, sensor compatibility, solution engineering and systems integration. Issues such as these become real barriers for complex applications such as Random Bin Picking

There is little doubt that Random Bin Picking (RBP) is a significant advanced manufacturing technology innovation. The key industry drivers for RBP include cost of manual operations, difficulty in material handling, and hazardous conditions. However the key drivers for Retrofitting are different; cycle time, error rates, down time and recovery processes. A common set of enablers to Robotic Retrofit experience would at the same time enhance additional innovations. We believe these enablers would also span multiple manufacturing sectors and would be of particular interest to the baseline infrastructural technology areas including measurements, performance metrics, test methods, and standards.

Reasons to deploy advanced manufacturing technology innovations include: sustainability, flexibility, agility, reconfigurability, additive manufacturing, lifecycle information exchange and management, science-based modeling and simulation, intelligence and optimization of manufacturing systems, high throughput, high-accuracy measurement technologies, automation and robotics with increased pace of innovation. A good robotic retrofit candidate will naturally address many of these points. A good random bin picking solution will focus on solving some of the more complex issues for manufacturing such as: flexibility, agility, and reconfiguration. However, critical factors that are harder to achieve and that remain barriers to deployment are, front end engineering in order to complete deployment, sustainable high throughput, rapidly deployable enhancements and innovations.

The front end application engineering includes: part programming, path planning, end effector design and build, sensor and controller integration and then the systems engineering to make the operation function as intended. We believe addressing all these front end technical barriers will dramatically improve the successful update of aging robotic deployments. It has been our experience just this year with a body assembly line in Ohio, that after the pain and agony of the “front end” the end result was beyond the customers expectation, in fact our retrofit of vision guidance to a 10 year old robot brought the solution beyond the original systems capability. However the weeks taken to get there were very costly.

“What are key drivers for advanced manufacturing technology innovation?”

1) We see a need for a new Vision Guidance Controller Architecture. With open standards that supports things like additive manufacturing, where vision guidance for example can also provide product quality and process validation. Higher speed device communication is critical to meeting throughput requirements. A more open solution would allow wider variety of sensors that could improve the accuracy as well.

2) We see a need for modeling and simulation research where standards for object representation and solid model exchange could enhance the use of dynamic simulation. Simulation when uses effectively can help prevent engineering errors and solution gaps, however the pain and cost to produce effective simulations remain too high for routine everyday use. A simple pick and place dynamic simulation with complete robot model data still takes several days to complete in the most crude representation.

“What are the most important areas where R&D is needed (particularly in measurement and standards) to overcome barriers and accelerate manufacturing technology innovation?”

1) We think an Adaptive Guidance Open Architecture standard could be a focus area that with Defense support and Manufacturing’s requirements could produce a serious dual use opportunity. Such an open standard would also allow a large body of research to produce innovation at a much increased pace.

2) We also think Modeling and Simulation should be supported by a standards effort for information exchange as well as performance measurements. With strong simulation capable of emulating complex and complete intelligent automation systems designs could be validated before code is completed or machines are built. Performance enhancements could be identified and validated very early in the deployment cycle. Saving time and money for all involved.

Where is the next innovation?

- Real-time instant sensor and device calibration process eliminate lengthy manual calibration processes. Embed calibration data such as fixed focal length or camera model specific information.
- Real-time instant object pattern/feature learning, detection, orientation and inspection, How all this gets done is the challenge, once we are able to rapidly retrofit and deploy complex robotic solutions like random bin picking this is where we will turn our attention.
- 3D Models of objects, workstations, devices, parts, environment and with dynamic information to drive simulations. We need solutions that can be engineered more accurately, and faster with validation of results before fully executed or deployed.
- Bundled mechanical software solutions. In random bin picking we have found that the end effector is as complicated to design as the vision guidance application. Plus the need for the vision sensor to have clear FOV is becoming more and more an issue. We see two innovations in the horizon that can help rapidly deploy RBP and other advanced automation. 1) define a set or range of end effectors that are grouped by capability, flexibility, dexterity, power and pre-engineer them with universal wrist attachments base don a standard. 2) split the sensor positioning from the point of action, this means develop a robot arm just to position the lens, then maintain the muscle action to a separate arm that is able to maneuver into tight positions without a camera hanging off the wrist or having to move to an awkward location to get an image then relocate to pick the part.

Sustainable Manufacturing

Vijay Srinivasan, NIST

After surveying thirty large corporations, a recent article in the Harvard Business Review declared that "there is no alternative to sustainable development"[1]. A parallel, more extensive study by MIT found that "there is a strong consensus that sustainability is having – and will continue to have – a material impact on how companies think and act"[2]. These dramatic developments owe to the fact that the manufacturing sector, represented by these companies, has a significant impact on the economy, society, and the environment around the world. Close to home, the U.S. manufacturing sector contributes 11% of the Gross Domestic Product (GDP) and provides 10% of the nation's workforce with high-paying jobs. It is also the largest consumer of energy (45%), the second largest consumer of mined materials (21%), a major producer of solid waste (10 trillion kg per year), and a significant user of hazardous materials – all of which are implicated in a growing number of environmental problems. These facts are not lost on the U.S. government. The U.S. Department of Commerce (DOC) recently named sustainable manufacturing as one of its key performance goals and called upon NIST to provide national assistance to realize this goal.

Recognizing the environmental impact of manufacturing and the products they produce, many countries and regions have introduced regulations such as RoHS (Restriction of Hazardous Substances), REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) and WEEE (Waste from Electrical and Electronic Equipment) that restrict the sale of products containing hazardous or prohibited substances. Additionally, many companies have introduced consumer-oriented labeling to indicate various aspects of sustainability in their products, including Energy Star and labels for recycled content and recyclability of products. Some of these labeling are mandated by governmental regulations. Even if many of these regulations are local, their implications on the manufacturing sector are global – for example, the U.S. manufacturers are scrambling to comply with the European regulations because they do not want to be locked out of that lucrative market.

As the U.S. manufacturing sector sells globally, it also sources globally. It manages a global supply chain in all four major phases of a typical product's life cycle: raw material selection, product realization, customer use, and material recovery. As the U.S. manufacturers and their global suppliers struggle with sustainability issues in the product life cycle, they are discovering that they need to measure, control, and manage sustainability in a complex mix of temporal (life cycle) and spatial (global supply chain) dimensions. Additionally, they have to respond to the impact of their actions on economical, social, and environmental issues in this complex space-time domain. Business executives often bemoan that "you are only as green as your supply chain"[3], and compare the global sustainability challenges of today to the 'total quality management' (TQM) challenges they faced nearly a quarter century ago[4]. They are also concerned about the dwindling supply of raw materials and resources (e.g., energy, water), and the sometime unfriendly sources of material supply.

At a recent summit organized by the DOC Sustainable Manufacturing Initiative,

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[1] "Why sustainability is now the key driver of innovation", Harvard Business Review, Sept. 2009, pp. 56-64.
[2] The business of sustainability, MIT Sloan Management Review Special Report, 2009.
[3] http://www.hbrgreen.org/
[4] "The green conversation", Harvard Business Review, Sept. 2008, pp. 58-62.

representatives of a broad spectrum of U.S. industries expressed their frustration over a vast number of inadequately defined measures of sustainability, the difficulties with collecting and exchanging sustainability information, and difficulties with working across enterprise supply chains to ensure meaningful improvements in sustainability and conformance to regulations.

These concerns were echoed with greater technical depth and clarity in a Sustainable Manufacturing workshop hosted by NIST soon afterwards. The NIST workshop attracted participants from large and small companies in the U.S. manufacturing sector (GM, Ford, GE, Xerox, Lockheed Martin, Rockwell Automation, P&G, Siemens, Harbec Plastics, Masco, URS), software vendors (Dassualt Systems, Siemens PLM, PTC), government (DOC, NIST, NASA, NSF), non-governmental organizations (WRI, NCMS, CAMDUS, ANSI, NACFAM, ASTM), and academia (Stanford, Purdue, Georgia Tech, RIT, U of Kentucky, Portland State U., Texas Tech).

Most of the industrial concerns and lessons learned were summarized in the industrial panel convened by the NIST Sustainable Manufacturing Workshop. Some of the messages were:

- Sustainability should start with leaders at the top. Also, bottom-up solutions are very useful and powerful (because people want to be part of the solution to an important problem).
- Educating suppliers on sustainability is important and is a challenge.
- Regulations drive a lot of engineering action – often, non-compliance is the fear that drives these actions.
- Branding is very important for business. Many companies are positioning themselves at the forefront of sustainability movement to protect and/or enhance their brands.
- Is sustainability an opportunity or cost? There was a general agreement that there is no choice but to treat it as an opportunity.

In the NIST Sustainable Manufacturing Workshop we found evidence that the more experienced manufacturing firms see opportunities in sustainability beyond mere compliance with regulations – in fact, they view this as a driver of innovation. They find that by adopting lean manufacturing practices they can reduce waste (a sustainability goal) while saving associated costs. They also see new market opportunities if they can introduce innovative materials, processes, and products to meet the global economic, societal, and environmental sustainability needs.

In the meantime, several non-governmental and standards development organizations are actively engaged in proposing and issuing guidelines, standards, and regulations. It was clear at the NIST workshop that they need some urgent coordination. Several academics have studied these problems and are trying to bring some order and understanding to various sustainability practices. It is encouraging to see that the academic community that studies these problems includes economists, who are proposing methods to monetize many of the sustainability metrics.

Based on the NIST Sustainable Manufacturing Workshop, the major challenges faced by the U.S. manufacturing industry in their pursuit of sustainability goals can be summarized as: (1) they are unable to accurately measure economic, societal, and environmental impacts and costs of their products during the entire life cycle and across their supply chain; (2) full life cycle analysis (LCA) of products requires new methods to analyze, integrate, and aggregate information across hierarchical levels, organizational entities, and supply chain participants; and (3) they lack neutral and trusted programs to demonstrate, deploy, and accredit new sustainable manufacturing practices, guidelines and methods.

Appendix V: NIST's Manufacturing Engineering Laboratory

The National Institute of Standards and Technology's Manufacturing Engineering Laboratory (MEL) served as the primary sponsor of this workshop. MEL promotes innovation and the competitiveness of U.S. manufacturing through measurement science, measurement services, and critical technical contributions to standards. MEL actively anticipates manufacturers' changing requirements and pushes beyond the state of the art to solve tomorrow's measurement and standards problems today.

Developed collaboratively with its external partners in industry, academia, and other government agencies, MEL measurement and standards solutions allow its customers to overcome barriers to product and process innovation, to share manufacturing information seamlessly and accurately, and to take full advantage of the latest technologies essential to their competitiveness and future success.

In sponsoring this workshop, MEL initiated an important discussion between manufacturing leaders on issues that those leaders feel need to be addressed at the plant level, at the industrial sector level, and at the national level. Additional detailed information on MEL can be found at: http://www.nist.gov/mel/