Findings from the NIST Extreme Manufacturing Workshop

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Extreme Manufacturing

Extremely Different
Extreme Manufacturing

Extremely Different

- Extremely Productive
- Extremely Sustainable/Green
- Extremely Agile
- Extremely Rapid
- Extremely Custom
- Extremely Small or Big
- Extremely Precise
- Extremely Weird
- Extremely ........
Extreme Manufacturing: What are the technology needs for long-term US manufacturing competitiveness?

Gating Issues

• What are the characteristics of US manufacturing that would make it radically different and more competitive in the future than it is today?
• What are the dimensions of performance (broadly speaking) that could make a big difference if pushed to extremes?
• What long-term technology advances are needed to make these new levels of performance possible?
• What are the technological barriers to achieving these innovations?
• How can the US build and use its innovative capabilities to foster the creation and implementation of future manufacturing leadership?
The Imperative: Why this is Important to the Future of the US?

- The US faces increasingly global competition as other countries seek to establish prominence in advanced manufacturing and the products.
- The US needs to offset the globalization of traditional manufacturing of products based on production of commodities by creating comparative advantage in high-value product areas based on product and processes innovation and the implementation of emerging technologies.
- This workshop aimed to define and focus US priorities on providing the means to effectively develop and implement new technology-based concepts for future US manufacturing as a basis for
  - High-value jobs
  - Wealth creation
  - Sustained economic growth
  - National security
Workshop Topic Areas

- Future intelligent manufacturing systems
- Extremely efficient and effective manufacturing: affordability & sustainability
- Frontiers of manufacturing science
- The future manufacturing enterprise
Future Intelligent Manufacturing systems

- Extremely agile, adaptive, responsive and robust manufacturing
- Rapid product realization: scale-up of new products based on emerging technologies and materials
- “Snap-together” modular process and system modeling and simulation building blocks
- Highly integrated control of complex, precise processes throughout distributed multi-level production
  - Multi-tiered intelligent and interactive collaboration environments and models
Starting Point for Future Intelligent Manufacturing Systems

What We Want
- Infinite Flexibility
  - Flexible Tooling
  - Smart Equipment
  - Automation
  - etc.

When We Want
- Agility
  - RT scheduling
  - RT ordering
  - RT Tracking
  - etc.

Where We Want
- Movability
  - Plant in a Box
  - After-sale Assembly
  - etc.

How We Want
- Green+
  - Energy
  - Environment
  - System Metrics
  - etc.

Dexterous Robots
Wireless [RFID+]
DVT in a Box – General Assembly
Modeling of Energy Consumption

What We Want
When We Want
Where We Want
How We Want

Infinite Flexibility
Agility
Movability
Green+

Flexible Tooling
Smart Equipment
Automation
etc.

RT scheduling
RT ordering
RT Tracking
etc.

Plant in a Box
Flexible Enterprise
After-sale Assembly
etc.

Energy
Environment
System Metrics
etc.

DVT in a Box – General Assembly
Modeling of Energy Consumption

What We Want
When We Want
Where We Want
How We Want

starting Point for Future Intelligent manufacturing Systems
Needs and Challenges for Future Intelligent Manufacturing Systems

Virtual R&D
- Missing tools
- Flexible materials
- Kinematics
- Ergonomics
- Fatigue
- Force

Physical R&D
- Robotic technology
- End effectors
- Vision systems
- Sensor integration

Network R&D
- Between processes
- Interoperability
- Standards
- Interfaces

How do we enable a petri dish environment for viral development of mfg physical systems like Automatic CNC…?

What technology (sensors, diagnostics and stds) need developed to achieve real time optimized intelligent mfg enterprise in the USA?

How do we enable a petri dish for viral development of mfg virtual systems and engagement of millions of brains?
Future Intelligent Manufacturing Systems

Technology Challenges: Physical

• Develop machines that take design data and automatically generate the whole manufacturing process
  – Information on tools and processes needs to be portable / shared
  – Share information among tools on factory floor via interoperability of tools from different vendors
  – Protocol for machine tool connectivity – similar to TCP/IP or XML

• Sensor / sensor systems and virtual sensors
  – Need to *affordably* sensorize the system
  – Synthesize from process without having actual sensor
  – Get customers the information as suppliers measure the parts

• Manage complexity of operation technology and tools
  – Hide complexity – structure design for production simplicity (Carver-Mead)
  – Usable tools and simple interfaces
  – Maintainable and affordable

• How to model and automate manufacturing of flexible components?
  – e.g. composite structures
Technology Challenges: Virtual / Network

- Integrate real time data and models for better decisions
  - Market / System / Supply “net” / Process
  - How can different models interconnect? What is business driver?
- Need new ways to share data
  - Common language that operates across tiers throughout the enterprise
  - Dynamically reconfigurable

**How to create a “manufacturing iTunes”?**

- Widely available apps
- Crowd sourcing
- Enabling participation of small manufacturers
- Foster manufacturing social networks
- Connect elements of the value chain
- Every piece of equipment becomes node on the internet
  - Protocols
  - XML + data vocabulary
- Capture sensor-based data from machines, make available to “cloud”
  - Smart people will develop apps to use data and improve processes
Future Intelligent Manufacturing Systems

Recommendations

Physical

• Establish the development of revolutionary machines and manufacturing processes as a National priority and overcome barriers to implement and use (risk)
• Create a network of national test beds to invent, create and build the ideal manufacturing space

Virtual

• Establish revolutionary manufacturing modeling and simulation capabilities with incentives to implement and use
• Create an “ecosystem” of virtual capabilities -- Manufacturing M&S development and implementation centers

Network

• Incentivize creative proposals
  – Crowd sourcing
  – X-prize
  – Apps store model
  – Collaboration forum
Extremely Efficient and Effective Manufacturing: Affordability and Sustainability

- Exceptionally competitive-affordable customized production
- 3D printing: From prototyping to manufacturing
- Extreme improvements in usability of advanced technology for small and medium-sized manufacturers
- Designed-in sustainability for value-based enterprises
- “Condominium” approach for dynamic, modular, affordable facilities infrastructure
**Challenge Areas for Affordability & Sustainability**

- **Affordability** - Ability to survive in the current economy
- **Sustainability** - Capacity to endure (survival in a different future)

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<td><strong>Robust Design Infrastructure</strong></td>
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<td>Holographic 3D lithography</td>
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<td>Tolerance / cost / performance tradeoff theory and methods</td>
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<td>Seamless interfaces between design &amp; manufacturing</td>
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<td>Enable Small / Medium design organizations</td>
<td>Rapid, test-free product development</td>
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<td>“Bit-programmable” shop floor</td>
<td>Ultra small design teams lowering barriers to entry</td>
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Breakout Session 2

Goals and Challenges

Goal 1: Real-Time Metrics During Operations
• Rigorous probabilistic predictive models, empirical data to support prediction, self-healing (reconfiguring) factories, and self-integrating systems

Goal 2: Design/Manufacturing Integration & Optimization
• Much more robust modeling, simulation and decision support capabilities based on understanding of tolerance, quality control, and cost modeling
• Product realization modeling and simulation with integrated data management, cost analysis, system of systems integration, and validation of models

Goal Three: Product Response Time to Market/User Needs
• Ideation and design tools integrated with production verification; affordable computing power to run M&S models available at all tiers, (availability of high performance computing for the masses); Wiki or distributed collaborative design
Goal 4: Mass efficiency .....at low quantities

- Virtual companies, customized design at all levels and scales; machines that certifies/inspects as it builds; code certification; affordable 3D processes

Goal 5: Sustainment of Long-life Systems

- Health management tools (for products and machines); reliability of flexible machines; built-in robustness; knowledge capturing

Goal 6: Sustainability (capacity to endure)

- Integrated production and facility simulation, viable replacements for toxics, renewable feedstocks, and Smart Grid for managing intermittent renewable energy
Recommendations

• Support cluster model for enhancing future US manufacturing productivity S&T (systems tech/productivity)
  – Demonstrator / centers of excellence
  – Public-private partnerships
  – Small business need to be able to connect more easily to USG and OEMs
  – Fraunhofer Institute model
  – DoD sponsored clusters in specific areas

• “Tech Wiki” / Clearinghouse for technical information (knowledge and innovation networks)

• Characterize manufacturing resources that provide visibility on the factory floor + systems level model

• Need a new generation of manufacturing engineers

• Benchmark existing manufacturing support / cluster support
Frontiers of Manufacturing Science: Self-assembly and Biomanufacturing

- Advanced bioscience and biosystems for manufacturing
- Computational biology for process control
- Precise, high volume directed self-assembly of multi-functional nano-microsystems
- Future additive manufacturing—new ways to create durable, high-quality functional parts
Goals

- Develop fundamentally new physical manufacturing processes:
  - Produce new materials with breakthrough properties
  - Step-level improvements in manufacturing precision
  - Develop new “generic” multi-product platform technologies
  - Extremely flexible processes
  - Minimal waste and energy consumption

- That create value for the future US economy
  - Minimize impact of labor cost
  - Take advantage of our sophisticated tech infrastructure and our venture investment ethos
Example of a New Material: Micro-Scale Truss Material

Alan J. Jacobsen, HRL

Customizable material properties
- Anisotropic
- Designed spatial variation
- Highly flexible, scalable, low cost production
- Platform technology enabling many products
- Mass customization potential
- Additive process - minimal waste
Example of a New Process: Atomically Precise Manufacturing
John Randall - Zyvex

APM is the integration of two known experimental techniques:
- The atomic precision removal of H atoms from a silicon surface
- Atomic Layer epitaxy: the deposition of a single layer of Si atoms

The process which happens in an ultra high vacuum consists of removing H atoms with a scanning tunneling microscope and then introducing a Si containing gas that deposits a single layer of H protected Si atoms.

The process is repeated to build up 3D structures.
Technical Challenges

- **In situ metrology** (optical / nano metrology)
- **Enhanced Material modeling** for functionally graded materials
- **Improved Process Modeling** including accurate physical property linkages to design tools.
- **High throughput additive processes**
- **Pilot development manufacturing facilities** to validate scale up
- **Better alignment efficiency/yield** (e.g., solution based self assembly)
- **High throughput programmable automated micro assembly**
- **Improved Human – Machine Interface understanding**
- **Improved computing capabilities** to understand physical limits / tradeoffs with respect to **speed** (throughput), **performance**, composition control and precision
- **Environmental Health and Safety** and social risks of new materials and processes
Advanced additive manufacturing processes that are sufficiently low cost to “democratize” manufacturing (Would need to produce high performance materials/multiple dissimilar materials / customizable with good precision)

Directed Self Assembly to bridge size scales and allow roll to roll process

Atomically precise manufacturing (3D / Atomically Precise/ top down control)

High precision manufacturing technology with less than 10nm feature size

Process scale up and integration for these emerging technologies based on proof-of-concept metrics

Synthetic Biology to manufacturing (for energy efficiency, tissue engineering, and as a flexible platform technology, e.g. tobacco plant foundry to make vaccines and proteins)
The Future Manufacturing Enterprise

- Dynamic collaboration across extremely complex multi-level, reconfigurable supply chains
- Rapid engineering and production of integrated high-confidence cyber-physical products and systems
- Tightly integrated design, test, validation across vastly distributed production environments
- Potential new game-changing production paradigms:
  - Digital direct manufacturing of complex products and assemblies
  - Service-oriented manufacturing
  - Cloud manufacturing
Future Manufacturing
Enterprise Goals

• Goal 1: Extremely rapid, accurate, and pervasive modeling and simulation capabilities
• Goal 2: Extremely integrated and data-rich supply chain management
• Goal 3: Extremely accessible collaborative processes
• Goal 4: Extremely innovative design, development and production methodologies
Breakout Session 4

Goal 1: Extremely Rapid, Accurate, and Pervasive Modeling and Simulation Capabilities

Objectives:

• Interoperable, pervasive, intelligent, physics-based, certifiable process model libraries
• Virtual product development and documentation system
• Model-based operations and enterprise
• Intelligent product definition: a model capable of driving all downstream applications
• Simulation-based concurrent engineering
• Single digital thread
Goal 2: Extremely Integrated and Data-Rich Supply Chain Management

Objectives:

- Model-ready supply network
- Architecture for integration of business operations and functions
- Dynamic supply-chain network design and management
- Early enterprise risk awareness
- Factory without walls
Goal 3: Extremely Accessible Collaborative Processes

Objectives:

• Data interoperability and modeling standards
• Community platform as a basis for shared apps, practices and training
• Shared cost of infrastructure to provide a low cost of entry to SMEs
• Service-oriented manufacturing
• Precompetitive development of tools (enterprise dashboards, supply chain modeling)
Goal 4: Extremely Innovative Design, Development and Production Methodologies

Objectives:

• Design
  – Intelligent conceptualization and visualization
  – Design to cost
  – Manufacturing intelligence: Dynamic response to demand with customer in the loop

• Development
  – Integrated, systems-based assessment of energy, sustainability, and demand
  – Knowledge based advisors (integration of modeling/simulation with on-the-ground knowhow)

• Production
  – Highly automated and agile factory floor
  – Real-time, requirements driven life cycle cost and risk awareness
  – Closed loop, deterministic manufacturing with health and performance prognostics
  – Manufacturing situational awareness
  – Advanced manufacturing technology
Recommendations:

“A national initiative for the development and support of the future manufacturing enterprise.”

Key elements of the initiative are:

- **Leadership**: Establish a leadership entity (e.g. NSTC, public/private forum, interagency working groups) to coordinate and facilitate future manufacturing enterprise research and activities

- **Vision**: Develop a Manufacturing Enterprise Vision 2020 that describes the, in more detail, future characteristics and outcomes of the manufacturing enterprise

- **Strategy**: Create a National Manufacturing Enterprise Strategy to achieve the 2020 vision

- **Research Agenda**: Collaboratively create a research agenda (following slides)

- **Infrastructure**: Develop and support the infrastructure that will realize the future manufacturing enterprise (standards, repositories, trust mechanisms)
Multiple Policy Approaches Should be Explored

- “SEMATECH” model for service-oriented manufacturing
- “Fraunhofer” model for sustainable manufacturing
- FFRDC-like models
- EU Framework
- X Prizes
- NSF Centers for basic manufacturing science and model development
- SME Extension services (MEP)
- Standards development
- Tech Transfer from Federal laboratories
- Facebook model for collaboration
Preliminary Conclusions

• Workshop identified imperatives for future US manufacturing R&D and implementation
• Breakout groups identified several major technology opportunities for US leadership in next-generation manufacturing
• Workshop is the beginning of an on-going process to establish a “community of interest” amongst industry-government-academia on future of US manufacturing
• Next steps
  – Consolidate and integrate recommendations
  – Drill down on technology and applications opportunities toward roadmaps and investment foci
  – Establish continued dialogue in the community
  – Work with others to establish leadership and focus--integrate with White House and across federal government to establish investment strategy for future of US manufacturing
Back-up