Clean Energy Smart Manufacturing Innovation Institute

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OUTLINE

• AMO – A brief introduction

• Manufacturing USA Overview

• Current Barriers and Opportunities

• Goals and focus of CESMII

• Smart Manufacturing Goals and Objectives
  • Global efforts and how to leverage

• Q&A
But before we begin-

So what is smart manufacturing?

It simply means creating new and additional jobs in US

Smart way to improve efficiency, productivity, and competitiveness (Xi more profit)

But I could not resist an alphabetical soup

SM = IoT+CPS+AI (ML)
Advanced Manufacturing
Office of Energy Efficiency and Renewable Energy

Coordination for:
• Reduction of duplication
• Translation of best practices
• Codifying universal models

Collaboration toward:
Common goal to collectively increase U.S. manufacturing competitiveness

Clean Energy Manufacturing Initiative
AMO: Three complimentary strategies

Technical Assistance: Direct engagement with Industry
- Driving a corporate culture of continuous improvement and wide scale adoption of proven technologies, such as CHP, to reduce energy use in the industrial sector

R&D Consortia: Public-Private consortia model
- Shared R&D Consortia offer affordable access to physical and virtual tools, and expertise, to foster innovation and adoption of promising technologies

R&D Projects: Bridging the innovation gap
- Research and Development Projects to support innovative manufacturing processes and next-generation materials
What is the role of Advanced Manufacturing Office?

What we do: Partner with industry, small businesses, universities, and regional entities to invest in emerging clean energy technologies.

Focus on reducing barriers to scale-up and adoption of emerging technology

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Focus is to address market failure of insufficient industry R&D in the “missing middle” or “industrial commons” to de-risk promising new technologies.
How do we connect: C and P – NSF Funded research

Observability, Learnability,
Controllability, Convergence
Stability, Data Driven
Reachability, M&S
V&V UQ, S/W defined systems

Observability of complex systems
Yang-Yu Liu, Jean-Jacques Slotine, and Albert-László Barabási

A quantitative description of a complex system is inherently limited by our ability to estimate the system's internal state from experimentally accessible outputs. Although the simultaneous measurement of all internal variables, like the metabolite concentrations in a cell, offers a complete description of a system's state, in practice experimental access is limited to only a subset of variables, or sensors. A system is called observable if we can reconstruct the system's complete internal state from its outputs. Here, we adopt a graphical approach derived from the dynamical laws that govern a system to determine the sensors that are necessary to reconstruct the full internal state of a complex system. We apply this approach to biochemical reaction systems, finding that the identified sensors are not only necessary but also sufficient for observability. The developed approach can also identify the optimal sensors for targeted or partial observability, helping us reconstruct selected state variables from appropriately chosen outputs, a prerequisite for optimal bioreactor design. Given the fundamental role observability plays in complex systems, these results also serve as a foundation under the broader of section 1). For a linear time-invariant dynamic system (3, 4),

\[ x(t) = A x(t) + B u(t) \]

and

\[ y(t) = C x(t) \]

reduce to the observability matrix \( O = \{ A, CA, CA^2, \ldots, CA^{n-1}\} \).

To simplify the observability analysis, we assume that we can monitor a selected subset of state variables, i.e.,

\[ y(t) = \{ y_1(t), y_2(t), \ldots, y_k(t) \} \]

which we call sensors. Observability of complex systems can then be posed as follows: Identify the minimum set of sensors from whose measurements we can determine all other state variables. Whereas (2) offers a formal answer to the observability issue in the context of small engineered systems, it has notable practical limitations for natural and complex systems. First, it can only confirm (or deny) if a specific sensor set can be used to observe a system, without telling us how to select it. Second, a brute-force search for a minimum sensor set requires us to inspect via (3) of about \( 2^k \) sensor combinations, a computationally prohibitive task for large complex systems. Thus, the work of this research provides a solution to the observability problem in complex systems.

Controllability of complex networks
Yang-Yu Liu, Jean-Jacques Slotine, & Albert-László Barabási

The ultimate proof of our understanding of natural or technological systems is reflected in our ability to control them. Although control theory offers mathematical tools for steering engineered and natural systems towards a desired state, a framework to control complex self-organized systems is lacking. Here we develop analytical tools to study the controllability of an arbitrary complex directed network, identifying the set of driver nodes with time-dependent control that can guide the system's entire dynamics. We apply these tools to several real networks, finding that the number of driver nodes is determined mainly by the network's degree distribution. We show that sparse heterogeneous networks which emerge in many real complex systems are the most difficult to control, but that
**Vision:** U.S. global leadership in advanced manufacturing

**Mission:** Connecting people, ideas, and technology to solve industry-relevant advanced manufacturing challenges, thereby enhancing industrial competitiveness and economic growth, and strengthening our national security.

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**Goal 1:**
Increase Competitiveness

**Goal 2:**
Facilitate Technology Transition

**Goal 3:**
Accelerate the Manufacturing Workforce

**Goal 4:**
Ensure Stable and Sustainable Infrastructure

*The four interrelated program goals. From 2016-2019 Strategic Plan*

Credits: Dr. Frank Gayle, AMNPO, NIST
Each institute has:

1) Clear, unique institute focus
2) Clear industry value proposition
3) Strong Partnerships
4) Ability to address critical challenges
5) A balanced portfolio of projects

Consortia are open—new members able to join
Progress to Date

- $600 million federal investment matched by over $1.3 billion non-federal
- Nine active institutes: 1,300 members, over 240 technology development projects.
  - Members include two-thirds of Fortune 50 U.S. manufacturers
  - 8 out of the 10 top-ranked research and engineering universities.
- Competitions underway for additional institutes

Manufacturing USA, A Third-Party Evaluation of Program Design and Progress, Deloitte Study, Jan 2017

Institutes are achieving high degrees of network connectivity and strong member recruitment, reaching respective “tipping points” that drive towards success. The number of members and degree of member connectivity are key indicators of the sustainability of an Institute’s network. There are early signs that Institutes are reaching “tipping points” where organizations see membership as necessary to their own success and seek out membership without being prompted.
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Barriers according to McKinsey Analysis

Manufacturers need to overcome major implementation barriers, of which some are more relevant for advanced players.

Top 5 barriers mentioned by manufacturers with no/limited progress in Industry 4.0

- Difficulty in coordinating actions across different organizational units
- Lack of courage to push through radical transformation
- Lack of necessary talent, e.g., data scientists
- Concerns about cybersecurity when working with third-party providers
- Lack of a clear business case that justifies investments in the underlying IT architecture

Additional top barriers mentioned by more advanced manufacturers

- Concerns about data ownership when working with third-party providers
- Uncertainty about in- vs. outsourcing and lack of knowledge about providers
- Challenges with integrating data from disparate sources in order to enable Industry 4.0 applications


Industry 4.0 after the initial hype Where manufacturers are finding value and how they can best capture it, McKinsey Global Institute
### The Age of Analytics: Competing in a Data-Driven World

There has been uneven progress in capturing value from data and analytics.

<table>
<thead>
<tr>
<th>Potential impact: 2011 research</th>
<th>Value captured %</th>
<th>Major barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location-based data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ $100 billion+ revenues for service providers</td>
<td>50–60</td>
<td>▪ Penetration of GPS-enabled smartphones globally</td>
</tr>
<tr>
<td>▪ Up to $700 billion value to end users</td>
<td></td>
<td></td>
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<tr>
<td><strong>US retail</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ 60%+ increase in net margin</td>
<td>30–40</td>
<td>▪ Lack of analytical talent</td>
</tr>
<tr>
<td>▪ 0.5–1.0% annual productivity growth</td>
<td></td>
<td>▪ Siloed data within companies</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ Up to 50% lower product development cost</td>
<td>20–30</td>
<td>▪ Siloed data in legacy IT systems</td>
</tr>
<tr>
<td>▪ Up to 25% lower operating cost</td>
<td></td>
<td>▪ Leadership skeptical of impact</td>
</tr>
<tr>
<td>▪ Up to 30% gross margin increase</td>
<td></td>
<td></td>
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<tr>
<td><strong>EU public sector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ ~€250 billion value per year</td>
<td>10–20</td>
<td>▪ Lack of analytical talent</td>
</tr>
<tr>
<td>▪ ~0.5% annual productivity growth</td>
<td></td>
<td>▪ Siloed data within different agencies</td>
</tr>
<tr>
<td><strong>US health care</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ $300 billion value per year</td>
<td>10–20</td>
<td>▪ Need to demonstrate clinical utility to gain acceptance</td>
</tr>
<tr>
<td>▪ ~0.7% annual productivity growth</td>
<td></td>
<td>▪ Interoperability and data sharing</td>
</tr>
</tbody>
</table>

1 Similar observations hold true for the EU retail sector.  
2 Manufacturing levers divided by functional application.  
3 Similar observations hold true for other high-income country governments.  

*Source:* Expert interviews; McKinsey Global Institute analysis  
*Credits:* McKinsey Global Institute
**CESMII Opportunities to US Competitiveness**

**Figure 1: Global CEO survey: Manufacturing powerhouse rank trending and future forecast**

**Figure 6: Global CEO survey: Drivers of global manufacturing competitiveness**

**Table 2: Global CEO survey: Ranking of future importance of advanced manufacturing technologies by executives**

<table>
<thead>
<tr>
<th>Advanced Manufacturing Technologies</th>
<th>US</th>
<th>China</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictive analytics</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Smart, connected products (IoT)</td>
<td>2</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Advanced materials</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Smart factories (IoT)</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Digital design, simulation, and integration</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>High performance computing</td>
<td>6</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Advanced robotics</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Additive manufacturing (3D printing)</td>
<td>8</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Open-source design/Direct customer input</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Augmented reality (to improve quality, training, expert knowledge)</td>
<td>10</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Augmented reality (to increase customer service &amp; experience)</td>
<td>11</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

Source: Deloitte Touche Tohmatsu Limited and US Council on Competitiveness, 2016 Global Manufacturing Competitiveness Index

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Considerations for Developing and Deploying Smart Manufacturing Technologies

- What is the problem and why is it hard?
- How is it solved today and what are the barriers?
- What is new and innovative in our approach?
- Why is it critical for the institute goals? Who will benefit?
  - Who are the cross-industry partners?
- What is our measure of success and what impacts it will have?
- How much it will cost and how long it will take?
- What are the risks and payoffs?
- What is our short-term, mid-term and long-term strategy for success?
What are the Goals and Focus of the Institute?

Optimize the energy efficiency and in general resource efficiency of energy intense/dependent manufacturing process

- How much energy efficiency can be achieved?
- What is the current state of the art?
- What is the new innovation?

increased productivity
improved energy efficiency
Cost reduction for installation

open and interoperable platform
plug and play connectivity
integration and customization
Let us look at RD&D Focus

Infrastructure Requirements

Process modeling & measurements

Prediction, Control and Optimization

Testbed Characteristics

Research (Development and Demonstration)

Hardware

Software

Infrastructure Requirements

High fidelity process modeling

Data driven models for optimization

Performance indicators

Choice of sensors and data acquisition

Process modeling and measurements

High fidelity process models

Advanced analytics and optimization

Modular reusable components

Verification and validation

Uncertainty quantification

Testbed requirements w.r.t ASCPMM

Testbed development and deployment
Let us look at OT&IT Focus

Technology (Operations & Information)

- Process Technology
- Open Standards
- Sensor technologies
- Data Analytics and HPC
- Testbed Architecture

Testbed Characteristics:
- Interoperability
- Scalability
- Reusability
- Security
- Risk management

Testbed requirements with respect to ASCPMM:
- Information Technology
- Operational Technology
- Integration of IT and OT

Testbed development and deployment:
- Virtual testbed using modeling and simulation
- Actual testbed in industry
Let us look at Workforce Development Focus

- Certification
- Learning Factories
- Train the trainers
- Curriculum
- Skills Development
- Training

Workforce Development (WFD)
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We will need a Reference Model for Smart Manufacturing

**Plan**
- Collaboration & Business Processes
  - Application
  - System Network
  - Data Infrastructure
  - Physical System

**Do**
- Control
  - (Analytics, Optimization)
  - (Shop floor-Supply Chain Integration)
  - (Model, Cloud computing, workflow)
  - (Things of IoT-Machines, Sensors, Actuators, Devices)

**Measure**
- Improve
What is the strategy for deployment through Testbed for Smart Manufacturing?

Concept of testbed for Smart Manufacturing Systems Integration

- Market and business drivers
- Specific System Application
  - Networked Enterprise A
  - Networked Enterprise B
  - Networked Enterprise C
- Replicable Testbeds
  - Testbed 1
  - Testbed 2
  - Testbed 3
  - Testbed 4
- Lab/Pilot study
- Enabling technology requirements
- New technology capabilities
- Knowledge Gaps about Technology
  - Technology A
  - Technology B
  - Technology C
- New insights
  - Analytics Algorithms
  - Sensing
  - Modeling and Simulation

Energy Efficiency & Renewable Energy
We need a Testbed Framework

<table>
<thead>
<tr>
<th>Levels*</th>
<th>Data</th>
<th>Motivation</th>
<th>Function</th>
<th>Network</th>
<th>Time</th>
<th>People</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Level</td>
<td></td>
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<tr>
<td>Process Level</td>
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<tr>
<td>Shop floor level</td>
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<tr>
<td>Plant Level</td>
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<tr>
<td>Extended Enterprise Level (Including supply network)</td>
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<tr>
<td>Deployed Testbed</td>
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</table>

*Testbed Architecture cell level description with respect to testbed characteristics and requirements could be based on Zachman Framework.

U.S. Department of ENERGY | Energy Efficiency & Renewable Energy
Zachman Framework – A good tool to use

<table>
<thead>
<tr>
<th>Data</th>
<th>Function</th>
<th>Network</th>
<th>People</th>
<th>Time</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Things</td>
<td>List of Processes</td>
<td>List of Locations</td>
<td>List of Organizations</td>
<td>List of Events</td>
<td>List of Business Goals</td>
</tr>
<tr>
<td>What</td>
<td>How</td>
<td>Where</td>
<td>Important to the Business</td>
<td>Important to the Business</td>
<td>and Strategies</td>
</tr>
</tbody>
</table>

Transformation is the key to bridging the perspectives

Each cell contains a single variable model
Based on the Testbed Framework let us look at OT&IT Integration

<table>
<thead>
<tr>
<th>OT</th>
<th>IloT</th>
<th>PCO</th>
<th>MS&amp;A</th>
<th>Data analytics</th>
<th>HPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>M2M</td>
<td>ICS</td>
<td>CPS</td>
<td>Security</td>
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<tr>
<td>Petroleum refining</td>
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<tr>
<td>Chemicals</td>
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<td>Metals manufacturing</td>
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<td>Food and beverage</td>
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<tr>
<td>Glass</td>
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<td>Pulp and paper</td>
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<tr>
<td>Discrete manufacturing &amp; Other opportunities</td>
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</tbody>
</table>
Let us look at an example for Model-based Advanced Analytics

1) Develop and Standardize Open Software and Communication Platforms,
2) Develop Advanced Sensors,
3) Develop Improved Real-Time Data Analytics and Control Systems,
4) Advanced High Fidelity Modeling,
5) Develop First-of-Kind Application Toolkits for SM Deployment,
6) Enable Availability of Appropriate Testbeds
We need Smart Data

Reduce the information overload. Can we get the same level of insights with smart data?

Data Volume

Past | Present | Future

Big Data

Current DA

Relevant and Useful Data

Reduce the information overload. Can we get the same level of insights with smart data?
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Platform Industry 4.0 – Based on RAMI 4.0

- connects embedded system smart production technologies and processes
- focuses on the end-to-end digitization
- digitizes the horizontal and vertical value chains

Working Groups
1. Reference architectures, standards and norms
2. Research and innovation
3. Security of networked systems
4. Legal framework
5. Work, education and training

http://www.plattform-i40.de/I40/Navigation/EN/ThePlatform/ActivitiesAndParticipation/activities-and-participation.html;jsessionid=8CB23AD28F96956A7090F270088C7E26
Reference Architecture Model Industry 4.0 (RAMI 4.0 (DIN SPEC 91345:2016-04 Standard))
The Industrial Internet Reference Architecture (IIRA) is a standards-based open architecture defined by the Industrial Internet Consortium (IIC).

Mapping of RAMI with IIRA

Standardization efforts

• Industrial Internet Consortium - The Industrial Internet Reference Architecture (IIRA) -
  http://www.iiconsortium.org/

• Platform Industrie 4.0, Reference Architectural Model Industrie 4.0 (RAMI 4.0),
  https://www.plattform-i40.de/i40/Redaktion/EN/Downloads/Publikation/rami40-an-introduction.pdf

• Predictive Model Markup Language (PMML) standard as well as Portable Format for Analytics (PFA) standard developed under Data Mining Group (DMG) - http://dmg.org/

• Technical standards for V&V under ASME V&V standards committee. Established a new sub-committee ASME V&V50 Verification and Validation of Computer Modeling for Manufacturing.-
  https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=101978604


• US VTAG for SEG 7 – Smart Manufacturing -The IEC transitioned Systems Group 8 Smart Manufacturing, into a new Systems Evaluation Group -
Inspired by considerations of value and use

Repeatable and Cost reducing Solution across industry sectors

(CESMII Role: Better Business models and Value Chain, Education and Training, OEM and Supply Chain Engagement for Testbeds and Open Standards Platform Implementation)

(CESMII Role: Reduce cost of Testbeds, Scaling up First-of-Kind Application Toolkits, Workforce Training, Open Standards Platform Implementation)

Adapted from: Donald Stokes (Pasteur's Quadrant: Basic Science and Technological Innovation, Brookings Institution, 1997)

Project Types:
- purely exploratory
- employ existing knowledge to solve SM problems
- create new SM technologies for their intrinsic interest
- create new technologies in close collaboration with members
List of references

- THE INTERNET THINGS BUSINESS INDEX A quiet revolution gathers pace A report from The Economist Intelligence Unit, https://www.arm.com/files/pdf/EIU_Internet_Business_Index_WEB.PDF
- Platform Industrie 4.0, http://www.plattform-i40.de/
- Industrial Internet Reference Architecture, https://www.iiconsortium.org/IIRA-1-7-ajs.pdf
Some Opportunities

Call for Papers

Submit your paper and advance the measurement science, standards and protocols, and tools needed to design, analyze, and control smart manufacturing systems based on a cyber-physical infrastructure for digital manufacturing.

Relevant Topics Include
- Information and domain specific modeling, semantics and architecture for manufacturing systems
- Cyber-physical infrastructure for design, analysis and control of smart manufacturing systems
- Model-based systems engineering and machine-to-machine communications
- Multi-layer networks and control
- Life cycle engineering and sustainability
- Supply chain modeling for smart manufacturing
- Real-time data analytics for predictive modeling for manufacturing system performance
- Uncertainty quantification and propagation including verification and validation
- Manufacturing process (continuous and discrete) characterization for sustainable manufacturing
- Material information modeling across the product life cycle
- Resiliency and recovery of smart manufacturing systems and supply chains
- Cloud computing and manufacturing services
- Digital manufacturing
- Digital thread for additive manufacturing

Editor-in-Chief
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“The science behind the standard [has] to be explained so that people can have trust in the standard. This journal was conceived to fill that gap and also to have an intersection of manufacturing science, information science and data science with focus on industry application.”
Dr. Sudhansu Rachuri

Benefits to Participants of Standards Participation
- Networking with the foremost technical experts in your field.
- Awareness of technical issues, and standards and best practices in your industry.
- Broader understanding of other segments of your industry worldwide.
- In some instances, fulfilling the requirements for professional development.

The initial founding members of this new committee include research experts from industry, academia, government, and industry consortia.

Benefits to Supporting Organizations and the Public
Organizations realize direct and indirect benefits when they support employees’ membership in ASME Standards & Certification activities, such as:
- Organization’s perspective considered in standards development and requirements.
- Enhancement of participating employees’ understanding of relevant standards.
- Access to opportunities for shared participation in research and development.

How to participate
Participation is simple. You need to submit an ASME Codes and Standards Personnel Form and ASME Codes and Standards Participation Acknowledgment Form. Please contact Martan Heller (M.Heller@asme.org, +1.222.591.8514) and she will help you with the process.

FAQs about Standards and Certification
http://tinyurl.com/osdideen

General Information on participation in Standards committee
http://tinyurl.com/plvsgme

https://cstools.asme.org/csconnect/CommitteePages.cfm?
Committee=101978604

http://www.astm.org/SSMS
Advanced Manufacturing Office (AMO) Multi-Year Program Plan For Fiscal Years 2017 Through 2021