Spinning a Standards-Based Digital Thread for Smart Manufacturing

Allison Barnard Feeney
Smart Manufacturing Operations Planning and Control Program Manager

Engineering Laboratory
National Institute of Standards and Technology
Outline

• NIST and Manufacturing
• Economics of the Digital Thread
• Standards for the Digital Thread
• NIST Digital Thread for Smart Manufacturing Project
• Summary
NIST and Manufacturing
NIST and Manufacturing

“It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing [...] than by the establishment of the [National Bureau of Standards].”
House Committee report, May 1900

NIST Mission: To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

A partner to US manufacturers for more than a century, NIST helps the nation’s manufacturers to invent, innovate, and create through:

- **Measurement science** – manufacturers and technology providers use NIST test methods, measurement tools, performance measures, and scientific data every day
- **Advanced materials** – NIST is building a materials infrastructure to accelerate the timeline from design to deployment of new materials
- **Standards development** – NIST provides the scientific and technical basis for voluntary consensus codes and standards
- **Partnerships** – collaborations with the private sector and academic organizations help advance and disseminate research and support US manufacturers
Why Manufacturing Matters

- $2.1T in value added to the U.S. economy
- **Highest multiplier effect** (3.6) of any economic sector
- 12.3 million manufacturing workers in the United States, accounting for 9 percent of the workforce
- In addition, manufacturing supports an estimated 18.5 million jobs in the United States—about one in six private-sector jobs
- **Output per hour** for all workers in the manufacturing sector has increased by more than 2.5 times since 1987

Manufacturing is a key driver of productivity growth, innovation, and trade
Economics of the Digital Thread
Economic Analysis of Technology Infrastructure Needs for Advanced Manufacturing

- **Objective** – Determine technology infrastructure needs to support advanced manufacturing.
  - NIST conducts such studies regularly to help inform NIST’s strategic planning and current/future investments.

- **Method** – Conduct qualitative and quantitative investigation of the barriers to adoption of smart manufacturing technologies and processes, with a focus on the underlying technology infrastructure.
  - Identify current and emerging trends related to smart manufacturing;
  - Identify technology infrastructure needs to support the development and adoption of smart manufacturing technology;
  - Document the challenges and barriers that inhibit the development of technology infrastructure;
  - Estimate the economic impact of meeting these technology infrastructure needs; and
  - Assess potential roles for NIST in meeting technology infrastructure needs and realizing economic benefits.

Economic benefits of meeting technology infrastructure needs for smart manufacturing are $57.4 billion per year.

Study Take-Aways for the Digital Thread

- Managing digital data streams through models ($8,922 M/year)
  What: CAD models, material characteristics, simulation models of part creation, plant layout
  Needs: High-fidelity process models, physical model representation for flexible objects, data standardization, standard and simpler equipment interfaces to facilitate consistent data entry, standard terminology for automated part costing

- Seamless transmission of digital information ($10,310 M/year)
  What: seamless sensor integration, interoperability between platforms, secure data transmission (wired, wireless)
  Needs: Secure data transmission; secure cloud computing and data sharing; standard communication protocols; retrofitable, plug-and-play data communications systems; data interoperability of 3D model parameters and product manufacturing information

- Efficient communication of information to decision makers ($7,717 M/year)
  What: easy-to-interpret, comprehensive interfaces, accessible from any location
  Needs: Common taxonomy across platforms and disciplines, standards in interface design for manufacturing equipment

Standards for the Digital Thread
## Types of Standards

<table>
<thead>
<tr>
<th>Process</th>
<th>ISO-9000</th>
<th>ISO 27001</th>
<th>ISO 50001</th>
<th>CMMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semantic Models</td>
<td>ISA 95</td>
<td>STEP</td>
<td>QIF</td>
<td></td>
</tr>
<tr>
<td>Transport Syntax</td>
<td>OPC/UA</td>
<td>MQTT</td>
<td>AMQP</td>
<td>MTConnect</td>
</tr>
<tr>
<td>Communication</td>
<td>TCP/IP</td>
<td>UDP</td>
<td>RS-422</td>
<td>XBee</td>
</tr>
<tr>
<td>Security</td>
<td>DES</td>
<td>SSL</td>
<td>TLS</td>
<td>KERBEROS</td>
</tr>
</tbody>
</table>

Will Sobel, AVM Task 3: Standards Development and Promulgation, NIST MBE Summit, April 13, 2016, Gaithersburg, MD
Challenges for Industrial Data Standards

• No "one model to rule them all." Choose best standards in domain.
• We need semantically rich data standards with context.
  • Context varies based on lifecycle phase (e.g., design, manufacturing, quality)
  • Context varies based on the level of interaction with data (e.g., systems, operations, enterprises)
• We need a normalized method for contextualizing data at different points of the lifecycle
• We need identifiers that persist across domains
• Move out of the weeds of a domain and think about inputs and outputs at the boundary of the domain
• Forget about the data format and think about what is being represented in the data
Standards Examples

• STEP AP 242 (ISO 10303-242) standard on Managed Model Based 3D Engineering
  • Provides for interoperability of Product Lifecycle Management (PLM) information to enable the “digital thread” of model-based information for manufacturing, to reduce costs and improve responsiveness.

• ANSI Quality Information Framework (QIF) standard
  • Streamlines the flow of quality information across the complete product-quality lifecycle.

• MTConnect
  • MTConnect streams data from running machines, controls, sensors, making shop data available in XML format for real-time data analysis.

• OMG Systems Modeling Language (SysML)
  • Extending SysML to enable integration of systems modeling and analysis
Digital Thread Project Results
Lifecycle Information Framework and Technology

FROM INFORMATION SILOS...

Design  Analysis  Manufacturing  Quality Assurance  Customer & Product Support

## Lifecycle Information Framework and Technology

<table>
<thead>
<tr>
<th>Product Lifecycle Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
</tr>
<tr>
<td>Analysis</td>
</tr>
<tr>
<td>Manufacturing</td>
</tr>
<tr>
<td>Quality Assurance</td>
</tr>
<tr>
<td>Customer &amp; Product Support</td>
</tr>
</tbody>
</table>

...TO LINKED DATA...

Lifecycle Information Framework and Technology

...WITH BUILT IN TRUST AND TRACEABILITY...

Lifecycle Information Framework and Technology

...FOR DRIVING APPLICATIONS WITH DATA!

PMI Validation and Conformance Testing

- Supporting PMI standards implementation in CAD
- Verified and validated representation of PMI concepts in CAD models

- \[ 15.0 \pm 0.05 \]
- \[ 0.12 \]
- Example presentation of GD&T annotation

<table>
<thead>
<tr>
<th>Overview of CAD Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representation Limitations only</td>
</tr>
<tr>
<td>No Limitations</td>
</tr>
<tr>
<td>Presentation Limitations only</td>
</tr>
<tr>
<td>Representation Level</td>
</tr>
</tbody>
</table>

- \[ \text{https://go.usa.gov/mGVm} \]
- \[ \text{https://go.usa.gov/yccx} \]
Design to Manufacturing and Inspection

• Proof-of-Concept demonstrator for standards-based transport of PMI downstream to manufacturing and First Article Inspections

• Reduced and/or eliminate recreation of part design data, reduce risk of error introduction downstream

• [https://go.usa.gov/xnc3v](https://go.usa.gov/xnc3v)

• Report: [https://go.usa.gov/xnc3f](https://go.usa.gov/xnc3f)

Digital Manufacturing Certificate Toolkit

- Toolkit includes a User Interface and API for Reading, Writing, and Verifying digital signatures in models.

- Supports G-Code (ISO 6983), QIF 2.0, PDF/PRC, and STEP P21 formats.

- Toolkit and source code available at: https://github.com/usnistgov/DT4SM
NIST Smart Manufacturing Systems Test Bed

- Reference architecture and implementation
- Rich source of data for fundamental research (TDPs with native CAD, STEP, MTConnect, QIF)
- Physical infrastructure for standards and technology development
- Demonstration test cases for education

- [https://go.usa.gov/xnqJr](https://go.usa.gov/xnqJr)
- Report: [https://go.usa.gov/xncc3](https://go.usa.gov/xncc3)
Monitoring Manufacturing Systems

- Simulated cycle time for feature was 15 seconds, but measured cycle time was 80 seconds. Feed rate mismatch affects production schedule

- Determine root cause of feed mismatch and remedy production scheduling issues

- Integrate multiple data sources (STEP, NC Code, MTConnect, QIF) from systems across the product lifecycle to determine causation using data analytics

- Report: https://go.usa.gov/xnccB
NIST-MTC Collaboration

• Contract design house (NIST) and OEM (MTC) relationship.

• The assembly was jointly designed, manufactured at NIST, inspected by both parties. MTConnect and QIF data was collected and analyzed.

• Data interoperability issues exist. Manual data manipulation was required.

• Persistent IDs are required to make all data traceable to the authority CAD model through all process steps.

• Paper forthcoming
Current work: System Lifecycle Handler

Requirements

• Identify artifacts and relationships in the digital thread
• Provide a unique global identifier system for the digital thread
• Provide a multiple-step resolver system for global identifiers
• Common handler system for global identifiers
• Search and query artifacts/versions in the digital thread
• Build a digital thread by establishing connections between artifacts
• Traceability, impact analysis, and continuous validation and integration of the digital thread
• Provide visualization/graph queries on the digital thread
• Expose the digital thread as an API
Summary

• Novel smart manufacturing technology infrastructure would save manufacturers $57.4 billion annually.
  • Conservative - methodology accounts for impact in a single year, but benefits would persist

• Barriers to innovation increase cost of R&D, disincentivize private investment, and magnify role of public institutions.
  • Potential adopters, uncertain of ROI, are unwilling to pay for novel features, which diminishes incentive to invest in the technologies.
  • Trusted third-party standards and performance data let adopters know what they are buying at various cost points

• Overcoming critical technical barriers may require investments in public-private manufacturing consortia.
  • We need open platforms and marketplaces where small players can innovate
  • Developing and disseminating technology infrastructure to support those platforms will require investments in both consortia and technology-extension services.

• Small enterprises face significant barriers to adoption of smart manufacturing technology.
  • Novel technology infrastructure that decreased the cost of software and implementation would increase adoption among SMEs,
  • Providing the technology infrastructure for cloud-based smart manufacturing, e.g., could make big data storage and analytics more accessible for SMEs.

• Technology infrastructure needs are vast and often interrelated
  • Unbalanced investment, closing some technical gaps while leaving other needs unmet, would likely fail to fully realize economic impact.

• Important areas where public sector can help: data analysis, cyber security, human capital, and interoperability of systems, machines, and other data streams.
Thank you!

https://go.usa.gov/xnqwy
Publication Search: https://go.usa.gov/xnc2e

Disclaimer: Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.