NIST Advanced Manufacturing Series 100-21

2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems

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National Institute of Standards and Technology
U.S. Department of Commerce
2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems

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U.S. Department of Commerce
Wilbur L. Ross, Jr., Secretary

National Institute of Standards and Technology
Walter Copan, NIST Director and Under Secretary of Commerce for Standards and Technology
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Abstract

This report summarizes the results from the 2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems, which was held at the National Institute of Standards and Technology campus in Gaithersburg, MD, on April 23-24, 2018. This was the fourth in this series of workshops begun in 2015 to foster a shared vision of a new Smart Manufacturing (SM) platform to support Composable Service-Oriented Manufacturing (SOM) systems. The purpose of the workshop series is to identify and discuss challenges in advancing the vision within the context of open cloud service platforms for Smart Manufacturing systems. Like the previous workshop reports, the document gives (1) summaries of presentations on Smart Manufacturing and the theme of Composable Service-Oriented Manufacturing systems, (2) summaries of the six breakout sessions, each providing a unique perspective on the theme, and (3) the key findings from the workshop.

Acknowledgements

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

Keywords


Acronyms

API – Application Programming Interface
ASME – American Society of Mechanical Engineers
ASTM – ASTM International (formerly the American Society for Testing and Materials)
BPCCS – Business Process Cataloging and Classification System
CAD – Computer-Aided Design
CAE – Computer-Aided Engineering
CPMS – Cyber-Physical Manufacturing Services
DMDII – Digital Manufacturing and Design Innovation Institute
ERP – Enterprise Resource Planning
IEC – International Electrotechnical Commission
IEEE – Institute of Electrical and Electronics Engineers
Executive Summary

The National Institute of Standards and Technology (NIST) hosted 2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems at its Gaithersburg, MD, campus on April 23-24, 2018. Over 100 experts from industry, government, national laboratories, and academia participated. This was the fourth in a new series of workshops begun in 2015 to foster a shared vision of a new Smart Manufacturing (SM) platform that will support Composable Service-Oriented Manufacturing (SOM) systems. The objectives of the workshop were to (1) help in creation of a roadmap for research in this nascent field; (2) inform future technical work; and (3) offer information to industry, government agencies, and other stakeholders focused on manufacturing systems integration.

The main premise of the workshop is that a revolutionary convergence of several technological advances such as enhanced networking, adaptive automation, cloud services, and data analytics will be applied to existing manufacturing operations to create Smart Manufacturing systems. Significantly, the systems of the future will be available through on-demand composition of focused apps or services. Such apps or services are cyber-physical applications focused on a single function, as opposed to large, monolithic, multi-functional applications. Manufacturers will access these as on-demand downloadable components or cloud services using a pay-as-you-go model which promises to lower barriers and reduce cost significantly.

However, as the variety of apps, services, and systems available through this new SM development model proliferate, so do the risks associated with using, managing, and integrating them. One way to reduce the risks is to ensure that there is an ecosystem of capable standards and technologies that enable the composition of these apps, services, and systems within a new SM platform.

The workshop participants continued to explore the needed technical foundation for the ecosystem of standards and technologies as well as the SM platform. In addition to the five working sessions from the previous year, the workshop added a new session on Data Analytics. These sessions are:

- **Smart Manufacturing (SM) Model-Based Message Standards Development (MBMSD)** focused on innovative modeling methods and tools for efficient development, use, and maintenance of message standards, which are key to scalable service-oriented integration.

- **SM Systems Characterization (SMSC)** focused on technical means and measurement methods that can be used to assess an organization’s manufacturing systems for readiness, capabilities, and maturity level in their plans to implement smart manufacturing.

- **Smart Manufacturing Reference Model and Reference Architecture (SMRMA)** focused on developing reference models and architecture to support integration of diverse machines and software vendors' applications, enabling smart manufacturing capabilities.

- **Smart Manufacturing Apps and Services Marketplaces (SMASM)** focused on the need for precise vocabularies, technologies, and interface standards for equipment and resources to allow apps and services interoperability, and market infrastructure and governance.

- **Industrial Ontology Foundry (IOF)** focused on exploring value and feasibility of standardization of concepts and relations describing the intended meanings within the industrial domain in a manner that enables computer reasoning and improves reasoning across data sources.

- **Data Analytics (DA)** focused on both technical and interface obstacles associated with manufacturers using cloud-based, data-analytics (DA) services.
As a theme this year, the workshop focused on the fast-changing landscape of technologies and standards impacting Composable Service-Oriented Manufacturing (SOM) systems. The main findings from the workshop include the following:

- **New promising technical capabilities continue to emerge.** Each session identified and discussed new technologies & standards, which the participants believe to be essential to their respective R&D areas.

- **Issues with adoption and integration of the technical capabilities are challenging.** As in the previous years, it is clear from the session discussions that adoption and inclusion of new technical capabilities within the manufacturing enterprise often carry prohibitive integration cost tags.

- **Industry-wide mobilization is needed to address the tough issues.** Because of the complexity and costs associated with adoption and integration of new technological capabilities, it is necessary to involve industrial communities to both develop and agree on industry-wide implementation approaches and standards. In addition, these complexities require that the industry stakeholders organize themselves and act efficiently.

- **Industry-wide road-maps should be developed to address the tough issues.** For the industry stakeholders to organize themselves in an optimal fashion, there is a clear need for developing and maintaining industry-wide R&D road-maps.

The workshop maintained coverage of the areas from the previous workshop and added the new Data Analytics area. The overall directions for the workshop and the sessions remained on course from the previous year.

The ultimate governance goal of the workshop series is to support the community to drive specific R&D projects to contribute to the vision of Composable SOM apps/services and systems. Future events, such as this series, are hoped to enable execution of collaborative R&D efforts with high probability of success.
1 Introduction

This report documents the fourth workshop in the workshop series on the topic of Composable Service-Oriented Manufacturing (SOM) systems. Here we give a summary of a longer motivation for Composable SOM systems\(^1\), followed by a description of the workshop and the report itself.

1.1 Background: Composable Service-Oriented Manufacturing (SOM) Systems

The pursuit of Smart Manufacturing (SM) and exploration of Service-Oriented Manufacturing (SOM) to enable SM continues to be of great interest to industry. The vision for SOM is that future cyber-physical systems will be available in small “apps” or “services” and assembled or re-configured economically to execute complex workflow processes. These small apps have been called “microservices” that perform specific business, technical, or operational services, and which are linked together by other applications or workflows.

However, using the existing approaches has resulted in SOM systems that are costly to manage. Changes to these SOM systems to meet dynamic and complex workflow-process requirements currently demand laborious, manual processes to adapt, or re-configure their component services.

Advances in integration approaches are needed for the vision of SOM-based SM to materialize. That, however, requires new capabilities, including (1) SOM services life-cycle management and (2) SOM ecosystems life-cycle management. The former includes requirements analysis, design, behavior analysis, provisioning, deployment, discovery, use, and decommissioning of services. The latter includes services composition, design of service ecosystem operations, and optimization of service ecosystem execution.

On the other hand, manufacturers are concerned about time and cost of using these new capabilities. That includes efficiencies of (1) searching for and discovering relevant manufacturing services, (2) integrating them in an interoperable way, and (3) re-configuring them to meet changing requirements. We refer to systems capable of efficiently addressing these concerns as Composable SOM Systems.

Achieving such Composable SOM Systems requires new technologies. A key part missing from existing technologies is methods that provide for (1) precise management of reference domain semantics and (2) reliable interpretation of context-specific domain information. Hereafter, we name these methods Reference Models Life-Cycle Management (RM LCM) methods. Without them, there will be no basis for Composable SOM systems.

Significant scientific and engineering work is needed for achieving RM LCM. Measurement science, including a testbed to support hypothesis testing and experimentation, is needed to establish basis for standards representations of manufacturing information and knowledge-bases. Formalization of these representations will build on results from logic and rule-based knowledge systems; taxonomy/ontology development; knowledge, taxonomy, and ontology management systems; category theory; and other areas.

Standards will be critical to move research results from the testbed into industrial use. They will enable the needed interoperability and provide guidelines for development and implementation of new technologies. Standards cover terminology, definitions, methodologies, metrics, specifications, testing, and other issues.

In summary, the underlying hypothesis for this workshop and the workshop series is that measurement science, information standards, and technology advancements are needed to deliver RM LCM methods that are necessary to enable Composable SOM Systems, and the vision of SOM-based Smart Manufacturing.

1.2 Workshop Motivation and Objectives

The National Institute of Standards and Technology (NIST) hosted the 2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems at its Gaithersburg, MD, campus on April 23-24, 2018. The event brought over 100 participants from industry, government, national laboratories, and academia to identify measurement science, standards, technology challenges, and research and development (R&D) needs for the vision of Composable SOM systems. The objectives were to:

- Serve as a building block for creation of a roadmap for research, by developing information on:
  - Goals for Composable SOM systems viewed from multiple perspectives;
  - Capability gaps preventing the goals of Composable SOM systems;
  - Technologies required to address the capability gaps;
  - Future measurement- and standards-related challenges for Composable SOM systems;
  - Research and development needed to address the challenges.
- Inform future NIST technical programs and strategic planning.
- Offer valuable information to government agencies and stakeholders focused on the challenging area of systems integration within manufacturing environments.

1.3 Workshop Technical Sessions

1.3.1 How were session topics selected?

An earlier workshop identified standards and technology R&D issues\(^2\) that prevent reaching our vision. The 2016 workshop started to address these issues through five separate breakout sessions. This year, we extended the coverage with an additional session. The following is a summary of the sessions.

1.3.2 Session descriptions

This report is based on workshop discussions within six technical sessions, each taking a separate perspective on developing and adopting new technologies and standards to achieve Composable SOM Systems. Common to their differing perspectives is that they explore knowledge-based modeling approaches to achieve reference model lifecycle management (RM LCM) methods. The knowledge-based modeling allows capture and sharing of both structured and unstructured descriptions and specifications of manufacturing systems, processes, and products in computer-processable forms. The computer-processable representations capture information, know-how, guidance, and standards that enable Composable SOM systems. The sessions were:

- **Smart Manufacturing (SM) Model-Based Message Standards Development (MBMSD) Methods** explored novel knowledge-model-based methods for conveying intended usage – both customization and context – for messages used by SOM Systems. This novel approach to specification is used to support new message standards life-cycle-management (MSLCM) capabilities.

- **Smart Manufacturing Systems Characterization (SMSC) Methods** investigated knowledge-model-based characterizations of the manufacturers’ maturity and technologies’ capabilities to implement composable

applications and SM systems. These novel methods will be utilized to support reasoning about the compositability of these technologies within Smart Manufacturing Systems based on their interface designs.

- **Smart Manufacturing Reference Models and Architecture (SMRMA)** brought together standards developers, technology providers, and manufacturers to discuss reference models and architecture of ICT-enabled smart manufacturing systems. In addition to briefing the existing development efforts on smart manufacturing reference models and reference architectures, the participants explored the feasibility of service-oriented architecture and how knowledge models could be used to specify services registration, discovery, orchestration, and data interchange for service-oriented manufacturing systems.

- **Smart Manufacturing Apps and Services Marketplaces (SMASM)** explored knowledge-model-based definitions of multiple aspects of SOM systems, apps, and marketplaces. These novel models will be utilized to support the identification and analysis of current technological and other challenges, as well as requirements from the stakeholders of Composable SOM Systems.

- **Industrial Ontology Foundry (IOF)** investigated new knowledge-model-based approaches to develop a collaborative framework and platform for submitting, validating, and sharing ontologies for the industrial and manufacturing domains. In this way, the knowledge will be captured and refined to facilitate smart manufacturing practices and resources.

- **Data Analytics (DA)** focused on both technical and interface obstacles associated with manufacturers using cloud-based DA services including matching specific, manufacturing problems to specific DA solution algorithms; and estimating uncertainties associated with using these algorithms.

1.3.3 Sessions charge

The workshop participants were given charge to discuss and report on the topics in their respective breakout sessions to support structured presentation of roadmap material for future road-mapping activity.

1.4 Workshop Report Organization

The ideas presented in this report reflect the different perspectives on the topic of Composable SOM Systems given by the workshop attendees. As such, they can, at best, be viewed as a representative sampling of the entire industry. We envision follow-on workshops in this series to refine the research roadmap material for Composable SOM Systems presented in this report. The organization of the report is as follows. Section 2 summarizes plenary presentations of the first day. Sections 3-8 represent the main content of the report and describe results of each breakout session. Section 9 offers conclusions of the workshop. Appendices provide additional information from sessions, including definitions of key terms describing Composable SOM Systems and presentation material from the first day of the workshop approved for publication by the authors.
2 Day 1 – Opening Plenary Presentations

2.1 Overview

The first day of the workshop was a plenary session dedicated to (1) presentations from industry, academia, and government describing key efforts to advance state of art and practice in Smart Manufacturing and (2) presentation by session chairs to describe updates and plans for breakout sessions.

2.2 Agenda

The table summarizes the activities of the first day.

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>9:00</td>
<td>Intro &amp; Welcome (Serm Kulvatunyou, Nenad Ivezic, Simon Frechette)</td>
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<tr>
<td>9:15</td>
<td>Keynote I – (Mike Molnar, NIST)</td>
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<tr>
<td>9:55</td>
<td>Keynote II – Lessons Learned from I4.0 at Land O’ Lakes (Mark Short, Land O’ Lakes)</td>
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<tr>
<td>10:35</td>
<td>Break</td>
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<tr>
<td>10:50</td>
<td>Marketplace Session Update (Thorsten Wuest – WVU &amp; Soundar Kumara – PSU</td>
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<td></td>
<td>Keynote III – Smart and Advanced Manufacturing Innovation in DOE, Sudarsan Rachuri, DOE</td>
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<tr>
<td>11:20</td>
<td>Presentation I - Smart Factory IT Promotion for SME and Standardization in Korea (Prof. DongHag Choi, KATS)</td>
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<tr>
<td>12:00</td>
<td>Reference Architecture Session Update (Yan Lu - NIST, David Noller - IBM) + Presentation (Prof. Cheng)</td>
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<tr>
<td>12:30</td>
<td>Lunch</td>
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<tr>
<td>2:00</td>
<td>Presentation II - Smart Factory: Manufacturing Execution Optimization (Leyuan Shi – U. of Wisconsin)</td>
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<tr>
<td>2:40</td>
<td>Smart factory experience in a Korean SME (Hyunbo Cho – POSTECH, Sang Ki Choi &amp; Young Zoo Kim – ShinsinSa)</td>
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<tr>
<td>3:10</td>
<td>MBMSD Session Update (Serm Kulvatunyou - NIST, Nenad Ivezic - NIST, and Scott Nieman - LoL)</td>
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<tr>
<td>3:30</td>
<td>Break</td>
</tr>
<tr>
<td>4:00</td>
<td>SMS Characterization Session Update (Kym Wehrle - DMDII, Michael Brundage - NIST)</td>
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<tr>
<td>4:30</td>
<td>IOT state of play (Jim Wilson - OAGi, Michael Gruninger - U Toronto)</td>
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<tr>
<td>5:00</td>
<td>Data Analytics Session Update (Al Jones-NIST, Willawan Onkham - UPS)</td>
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<tr>
<td>5:30</td>
<td>Adjourn</td>
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2.3 Presentation Summaries

**Keynote I: Manufacturing USA & DMDII (Mike Molnar, NIST)**

This keynote discussed a national effort to raise the innovation potential of nationwide manufacturing capacities and consisted of three parts. First was an overview of Manufacturing USA – the national network for manufacturing innovation. The second described operation of one of the institutes in the network – the Digital Manufacturing and Design Innovation Institute (DMDII). The third summarized the status of the network today.

**Keynote II: Lessons Learned from I4.0 at Land O’ Lakes (Mark Short, Land O’ Lakes)**

This keynote described the mission of the Data-to-Value programmatic effort within Land O’ Lakes’ journey to achieve its Industry 4.0 (I4.0) vision. The mission is to enable a culture of data-driven decision making balanced with business expertise and intuition. The desired outcome is to unleash the power of analytics by collaborating with the Business and IT operating units of the company to identify opportunity, focus efforts, and deliver value in support of Land O’ Lakes’ broader growth objectives.
Marketplace Session Update (Thorsten Wuest – WVU & Soundar Kumara – PSU)

In this session update, the potential and status of smart manufacturing apps and service marketplaces were discussed. The aim of the session was to work towards a shared, secure, open-access infrastructure rich in functionality for easier systems integration and composability to be able to drive technological capability beyond just products by integrating services on standards, uncertainty quantification, benchmarking, performance-use metrics, systems modeling, and many more. A special focus of this year’s workshop was on current technological and other challenges, interoperability and security issues, as well as requirements from the stakeholders’ (e.g., designers’, providers’, and users’) perspectives.

Keynote III: Smart and Advanced Manufacturing Innovation in DOE (Sudarsan Rachuri, DOE)

The keynote described some of the on-going activities in the Advanced Manufacturing Office (AMO) of Energy Efficiency and Renewable Energy at the Department of Energy (DOE). It discussed the AMO from the point of view of its three strategies of (1) Technical Assistance, (2) R&D Consortia, and (3) R&D Projects. Technical Assistance is driving a corporate culture of continuous improvement and wide-scale adoption of proven technologies to reduce energy use in the industrial sector. Shared R&D Consortia offers affordable access to physical and virtual tools, and expertise, to foster innovation and adoption of promising technologies. Research and Development Projects supports innovative manufacturing processes and next-generation materials. Current barriers and opportunities were discussed along with details of several on-going activities.

Presentation I: Smart Factory IT Promotion for SME and Standardization in Korea (Prof. Dong-Hag Choi, KATS)

The presentation discussed on-going developments in Korea, including an adoption of Industry 4.0, manufacturing innovation strategy, the Smart Factory Foundation effort, and a number of case studies from these efforts.

Reference Architecture Session Update (Yan Lu – NIST & David Noller – IBM)

This session update discussed requirements on production plants, supply chains, and logistic systems to be flexible in design and reconfigurable “on the fly” to respond quickly to customer needs, production uncertainty, and market changes. Service-Oriented Architecture (SOA) is a promising approach to achieving such manufacturing agility. It has proven effective for business process adaption and – especially when combined with emerging Internet of Things (IoT) technology and the concept of cyber-physical production systems – is expected to similarly revolutionize real-time manufacturing. This session aimed to bring standards developers, technology providers, and manufacturers together to discuss impacts of ICT technologies on the emerging manufacturing systems architecture.

Presentation II: Smart Factory: Manufacturing Execution Optimization (Prof. Leyuan Shi, University of Wisconsin)

Many manufacturing firms use aggregated data to provide scheduling/decision solutions for handling their daily operations. Given the nature of shop floors operating in real time, these average-based scheduling systems cannot be fully executed since unexpected events such as rush orders, design changes, machine breakdowns, defective parts, and delivery delays, etc., are almost inevitable. Currently, shop floors respond to unexpected events via manual rescheduling or by spreadsheet, which leads to poor predictability and visibility of performance, slow response to uncertainties and market changes, and low efficiency of their production and supply chain systems.

In this talk, Manufacturing Execution Optimization (MEO) technologies developed by Dr. Shi and her team were presented. MEO will enable the production system to be smart. By establishing top-floor to shop-floor communication in real time, manufacturing firms will be able to significantly improve their production and supply
chain efficiency while responding to changes and disturbances in the most time-optimal manner. The presentation also briefly reviewed the history of software in Manufacturing and recent trends in software development outside of Manufacturing to propose a new model for Industry 4.0. An example covering Scheduling & Planning optimization was presented.

**Smart Factory Experience in a Korean SME (Prof. Hyunbo Cho, POSTECH; Sang Ki Choi & Young Zoo Kim, ShinShinSa)**

This presentation discussed experiences of a Korean small-or-medium (SME) manufacturing. ShinShinSa is a globally operating company that produces and supplies major press forming and assemblies for its products. The company has small-to-large press machines and a variety of high-tech production machines, inspection equipment for quality assurance, and facilities to manufacture and maintain molds.

**Model-Based Message Standards Session Update (Serm Kulvatunyou & Nenad Ivezic – NIST; Scott Nieman – Land O’ Lakes)**

The session update discussed the objective of seeking to advance the methodology for messaging standards (e.g., OAGIS) development and usage. The vision of the group is to develop model-driven methods and tools that drive more effective and easier-to-use message standards. Latest developments, such as business process context-based usage and life-cycle management of messaging standards were discussed.

**Characterization Session Update (Kym Wehrle – DMDII, Michael Brundage – NIST)**

Harmonization of digital assessment tools is needed to accelerate the adoption of digital technologies within the industrial base and Department of Defense. A number of organizations are funding projects to better understand their current digital state and the implications of adopting digital technology within their operations. This session update explored the activities required to harmonize common digital technology principals, approaches, and tools to ultimately strengthen U.S. manufacturing competitiveness.

**Industrial Ontologies Foundry (Jim Wilson – OAGi, Michael Gruninger – University of Toronto)**

The session update focused on the formation of an Industrial Ontologies Foundry (IOF), a new effort for converging existing semantic representations from the industrial and manufacturing domain. The primary purpose of the IOF is to develop a collaborative framework and platform for supporting development, submitting, validating, and sharing of ontologies for the industrial and manufacturing domains. In this way, knowledge can be captured in a common semantic form and shared to facilitate smart manufacturing and optimize other industrial practices and uses of resources along the lifecycle of a manufactured product. This year’s session reviewed the structure of this new organization, what we’ve learned from an initial proof-of-concept effort, and the principles and processes that should be used by the IOF to deliver value to the manufacturing industry.

**Data Analytics Session Update (Albert Jones – NIST & Willawan Onkham -- UPS)**

This session update focused on both technical and interface obstacles associated with manufacturers using cloud-based DA services. The session discussed solutions to four such problems. The first involves matching specific manufacturing problems to specific DA solution algorithms. For example, what kinds of manufacturing problems are best solved using neural networks and how can we choose an appropriate algorithm for the available data. The second involves estimating uncertainties associated with using those algorithms, software implementations of the algorithms, and any exogenous factors impacting the results. The third involves extending the existing predictive model markup language (PMML) to include standardized guidelines for helping manufacturers create the models and training data needed to use PMML. The fourth topic involves measuring the accuracy of DA models in the real-
world of manufacturing. It is impossible to build a completely error-free DA model. This is true regardless of (1) the amount, type, and quality of the input data and (2) the complexity of the manufacturing. It goes without saying, that the ability to measure that accuracy is critical.
3 Model-based message standards development

3.1 Overview

More automation is needed to increase integration efficiency, agility, and resilience of manufacturing enterprises. High-quality message standards and their development and usage methods within service-oriented manufacturing systems are essential to the automation. This, however, requires new tools and methods for specification of service requirements and capabilities.

This session reviewed on-going work to revolutionize the way message standards are collaboratively developed and used. New model-based architecture and systems engineering approaches were explored. These approaches are expected to create reference models and analysis and synthesis tools to serve as a basis of requirements and capability specification for manufacturing services. Such reference models and associated tools allow syntax-independent and business-process-first standards development and usage to become a reality. The new models and tools reduce manufacturing applications integration risk and costs to software providers and manufacturer users, promote standards adoption, and lead to more efficient and automated integrations.

The current progress within the OAGi Semantic Refinement Method and Tool (SRT) Working Group and OAGi Smart Manufacturing (SM) WG was presented. Recent use-case scenarios across the two efforts have been reviewed. In addition, the OAGi Small and Medium Enterprises Working Group activities were reviewed. The meeting objective was to arrive at a focused set of requirements for the three working groups to address over the next six months to one year, as well as beyond.

3.2 Agenda

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<tr>
<th>Time</th>
<th>Title</th>
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<tbody>
<tr>
<td>9:00</td>
<td>Introductions</td>
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<tr>
<td>9:15</td>
<td>Smart Manufacturing Requirements: Smart Mfg. WG update</td>
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<tr>
<td>9:45</td>
<td>Small &amp; Medium Enterprises Requirements: SME WG update</td>
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<tr>
<td>10:15</td>
<td>Contextualization Needs: BPCCS status &amp; update</td>
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<tr>
<td>10:45</td>
<td>Break</td>
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<tr>
<td>11:15</td>
<td>Semantic Refinement Tool (SRT) status &amp; update</td>
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<tr>
<td>12:00</td>
<td>Discussion</td>
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<tr>
<td>12:30</td>
<td>Lunch</td>
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<td>2:00</td>
<td>Next steps for MBMSD</td>
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<tr>
<td>3:30</td>
<td>Session Ends</td>
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3.3 Participants

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<tr>
<td>Scott Nieman</td>
<td>Land O’ Lakes</td>
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<td>Marija Jankovic</td>
<td>University of Macedonia, Greece</td>
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3.4 Highlights

Session highlights include the following:

- Manufacturing data integration models have changed radically with the introduction of the Industrial Internet of Things (IIoT). While, traditionally, manufacturing integration models represented bottom-up hierarchical data integration, with IIoT integrated into manufacturing information systems, real-time (streaming) data at lower layers can be integrated directly to higher layers or clouds, which can be accessed by all layers.
- An ongoing challenge is the lack of standards guiding integration of IIoT data directly into the business layer and how to fuse business information with IIoT data.
- There is lack of standards guidance on representing IIoT data and integrating the data with business-level messages.
- There is an ongoing effort to combine OAGi and MIMOSA standards to address this lack of standards and guidance. OAGi is an industry consortium dedicated to reducing the cost of integration by developing inter-operable, cross-functional, cross-industry, data-model-driven, and extensible standards to meet the challenge of a rapidly-changing global digital economy. MIMOSA is an industry association dedicated to developing and encouraging the adoption of open, supplier-neutral, standards enabling physical asset lifecycle management spanning manufacturing, fleet, and facilities environments.
- There is an ongoing effort at OAGi to advance manufacturing applications integration capability at Small and Medium Enterprises (SMEs).
- The intent behind the SME-focused effort is to describe a plan for an ‘SME Starter Pack’ and its OAGIS standard deliverables, to analyze benefits and costs of the ‘SME Starter Pack’ plan, and to develop an initial SME Starter Pack Proof-of-Concept.
- Business Process Classification and Cataloguing System (BPCCS) was prototyped for OAGIS business scenario documentation by adding business process context definition and keeping the definition with BPMN business process models corresponding to OAGIS scenarios.
- The role of the NIST-developed Semantic Refinement Tool (SRT) is to provide a common methodology, to establish a shared data architecture, and to allow collaboration among developers and users of message standards.
- SRT is used today in the agriculture sector to create integration artifacts to achieve greater efficiencies in message standards development. Efficiency gains have been reported also in the aerospace sector.
- There are on-going advanced SRT enhancement efforts, such as generation of JSON schemas.
3.5 Conclusion

The following table summarizes the identified issues and opportunities and respective submitters. The items represent a focused set of requirements for the OAGi Semantic Refinement Tool and Smart Manufacturing groups to address within the next six months to one year, and later.

<table>
<thead>
<tr>
<th>Item #</th>
<th>Issue/Oportunity</th>
<th>Submitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Support to generate B2IMML using JSON Schema</td>
<td>Dennis Brandl</td>
</tr>
<tr>
<td>2</td>
<td>User stories/use cases explaining Smart Manufacturing needs</td>
<td>Nikola Stojanovic</td>
</tr>
<tr>
<td>3</td>
<td>Define Smart Manufacturing architecture to analyze user stories/use cases</td>
<td>Nikola Stojanovic</td>
</tr>
<tr>
<td>4</td>
<td>Increase usability of BPCCS tool</td>
<td>Marija Jankovic, Thomas Knothe</td>
</tr>
<tr>
<td>5</td>
<td>Enable BPMN model introspection in BPM tools (e.g., BPCCS, Trisotech tools)</td>
<td>Scott Nieman</td>
</tr>
<tr>
<td>6</td>
<td>BPCCS tool functionality enhancement: advanced search, cross-referencing classification schemas, context reasoning</td>
<td>Marija Jankovic</td>
</tr>
<tr>
<td>7</td>
<td>BPCCS validation</td>
<td>Marija Jankovic</td>
</tr>
<tr>
<td>8</td>
<td>SRT-BPCCS Integration</td>
<td>Scott Nieman</td>
</tr>
<tr>
<td>9</td>
<td>Opportunity to apply BPCCS to Modular shop-floor IT (R&amp;D)</td>
<td>Marija Jankovic</td>
</tr>
<tr>
<td>10</td>
<td>Represent BPCCS meta-model using eBIM metamodel profile</td>
<td>Nikola Stojanovic</td>
</tr>
</tbody>
</table>
4 Smart Manufacturing Systems Characterization

4.1 Overview

This session explored the activities required to harmonize common digital technology principals, approaches, and tools to ultimately strengthen U.S. manufacturing competitiveness.

Harmonization of digital assessment tools is needed to accelerate the adoption of digital technologies within the industrial base and Department of Defense. A number of organizations are funding projects to better understand their current digital state and the implications of adopting digital technology within their operations.

The objective of the workshop was to:

1. Review and gather feedback on current and developing assessment tools and the driving organizations behind the development and facilitation of the assessments
2. Identify users of the assessments and define end-user objectives of the tools to refine and inform digital assessment harmonization road mapping efforts
3. Identify requirements of the digital assessment harmonization output (e.g., digital taxonomy of organizations and assessments, interactive web-based tool, etc.).

Given the wide range of assessments available, the workshop determined how various assessments were interrelated. The participants discussed the variability between the tools and the challenges of implementing. The uncertainty in determining which tool to use and the amount of resources being dedicated by various organizations in creating new maturity models was also addressed.

4.2 Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>Welcome &amp; Overview of the Day</td>
</tr>
<tr>
<td>9:30</td>
<td>Review and gather feedback on current development of assessment tools</td>
</tr>
<tr>
<td>10:00</td>
<td>Inform digital assessment harmonization road mapping: use case identification</td>
</tr>
<tr>
<td>10:45</td>
<td>Inform digital assessment harmonization road mapping: Use case + Assessment Gap Analysis</td>
</tr>
<tr>
<td>12:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>2:00</td>
<td>Identify requirements of the digital assessment harmonization output</td>
</tr>
<tr>
<td>3:30</td>
<td>Joint Session and Panel Discussion</td>
</tr>
</tbody>
</table>

4.3 Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael Brundage</td>
<td>NIST</td>
</tr>
<tr>
<td>Quanri Li</td>
<td>NIST</td>
</tr>
<tr>
<td>Kym Wehrle</td>
<td>DMDII</td>
</tr>
<tr>
<td>Roy Whittenburg</td>
<td>MBD360 LLC</td>
</tr>
<tr>
<td>Sangsu Choi</td>
<td>IGI, LLC</td>
</tr>
<tr>
<td>Hyunbo Cho</td>
<td>POSTTECH</td>
</tr>
</tbody>
</table>
4.4 Highlights

The session highlights include:

- Current maturity models do not consider impact of business factors. More Return on Investment (ROI) studies are needed.
- A need exists for an unbiased accreditation process for assessments.
- Current maturity models need to be classified by the purpose of the assessment.
- There is a gap in the interoperability of the current assessments. Studies are needed on how much they overlap.
- Future assessments should incorporate actionable outcomes in the form of dashboards and measurable metrics.
- Ownership of various assessments should be clear. The roles of organizations that integrate new technologies/standards into the assessments versus the organizations that disseminate/execute the assessments need to be clearly defined.
- The sources of data need to be defined. Are the data sources automated? Who owns the data? How is the data classified? These questions need to be answered in future assessments.
- Assessments should be classified based on output: checklists, report based, prioritized assessment list, taxonomy of assessments and resources, web-based tools.

4.5 Conclusion

The following table summarizes the needs and priorities for assessment options in smart manufacturing.

<table>
<thead>
<tr>
<th>Output</th>
<th>Rank</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action based recommendations (improvement plan, wizard function)</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>ROI/Business case for recommendations (high/low risk profiles for activities)</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Must provide rational of output (the why behind the recommendation)</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Best practice for each level of maturity</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Diagnostic tool that adapts to business</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Centerial location for all assessments</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Web-based interactive portal</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Plug in tools to assessment for an &quot;auto&quot; assessment</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Outline that provides high level first and allows one to drill down into details</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Adaptable by domain/industry</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Need to take multiple inputs prior to aggregation data</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>scalability</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Identify lead times, est. costs of capability implementation, how capabilities build upon one another</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Cloud-based tool/mobile tool</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Web interface w/ interview + admin features</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Rate assessments for comprehension</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Underlying logic so you can interrelate assessment outputs</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>
5 Smart Manufacturing Reference Model and Reference Architecture

5.1 Overview

Future manufacturing must become “smart” – capable of agilely adapting to a wide variety of changing conditions. This requires production plants, supply chains, and logistic systems to be flexible in design and reconfigurable “on the fly” to respond quickly to customer needs, production uncertainty, and market changes. Service-Oriented Architecture (SOA) provides a promising approach to achieving such manufacturing agility. It has proven effective for business process adaption and – especially when combined with emerging Internet of Things (IoT) technology and the concept of cyber-physical production systems – is expected to similarly revolutionize real-time manufacturing.

This session brought standards developers, technology providers, and manufacturers together to discuss impacts of information and communication technologies (ICT) on the emerging manufacturing system architecture. More specifically, we would like to explore how SOA can help integrate IoT, digital factory, and cloud computing technologies into modern manufacturing environments and enable manufacturing systems to respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.

The envisioned outcomes of this break-out session were the surveys of existing smart manufacturing reference models and reference architectures from industry and SDOs and a feasibility analysis of applying SOA to integrate shop-floor automation systems with enterprise software systems in smart manufacturing environments. Challenges were identified for implementing SOA-based smart manufacturing systems and standards in support of such implementations.

5.2 Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00-9:20</td>
<td>Review and discussion of the previous workshop results and developments since</td>
</tr>
<tr>
<td>9:20-9:45</td>
<td>Lot-Size of One: The Role of Open-Architecture Products and Services</td>
</tr>
<tr>
<td>9:45-10:10</td>
<td>The Smart Manufacturing Platform-AMCoT and its Automated Construction Scheme of Cloud Manufacturing Services</td>
</tr>
<tr>
<td>10:10-10:35</td>
<td>A Study on Utilizing Maturity Model for Finding Suitable Manufacturing Services</td>
</tr>
<tr>
<td>10:35-10:50</td>
<td>Condition-based Production Control for Cyber-Physical Manufacturing Systems</td>
</tr>
<tr>
<td>11:15-11:40</td>
<td>An Optimization framework for &quot;Production as A Service&quot; and Agent based Manufacturing</td>
</tr>
<tr>
<td>11:40-12:05</td>
<td></td>
</tr>
<tr>
<td>12:05-12:30</td>
<td>Decentralized Service Oriented Manufacturing System – The Machine’s Point of View</td>
</tr>
<tr>
<td>12:30-1:30</td>
<td></td>
</tr>
<tr>
<td>1:30-3:30</td>
<td>Discussions for SOASM</td>
</tr>
<tr>
<td>3:30</td>
<td>Session Closed</td>
</tr>
</tbody>
</table>
5.3 Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yan Lu</td>
<td>NIST</td>
</tr>
<tr>
<td>Mohsen Moghaddam</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Hung</td>
<td>Chinese Culture University, Taiwan</td>
</tr>
<tr>
<td>Kiyotaka Takahashi</td>
<td>Hitachi</td>
</tr>
<tr>
<td>Dennis Brandl</td>
<td>BR&amp;L Consulting</td>
</tr>
<tr>
<td>Kira Barton</td>
<td>University of Michigan</td>
</tr>
<tr>
<td>Feng Ju</td>
<td>Arizona State University</td>
</tr>
<tr>
<td>Binil Starly</td>
<td>North Carolina State University</td>
</tr>
</tbody>
</table>

5.4 Highlights

The session highlights include the following:

- The goal of service-oriented architecture for smart manufacturing (SOASM) is to realize adaptive factory, agile/collaborative manufacturing, mass customization/individualization, and enable a secure manufacturing environment.
- The benefits of SOASM include: improved OEE, fast SME entrance into market, reduced cost, and improved quality.
- Current manufacturing systems, where diverse applications exist, and endless spreadsheets are used for information exchange, are not designed for SOA.
- There are overlaps among the functionality of the applications but there is a lack of modular design of the functions.
- Enterprise-level SOA applications are prevalent in practice, while micro-service architecture is emerging for enterprise integration.
- Huge gaps exist between big OEM and SME capabilities to adopt SOA integration.
- Full adoption of SOA in manufacturing will first be achieved at higher smart-manufacturing function levels, such as ERP and MOM.
- Existing SOA-based smart-manufacturing-enabling standards include ISA 95/88/106, OPC UA, RESTful, SOAP, MQTT, AQMP, DPWS, MTConnect, ISO/IEC JT1 SOA architecture, IEEE/IEC TSN, ZVEI MTP, NAMUR, OPAF TRM, OAGIS, MESA B2MML, BPMN.
- Other enabling technologies include: IoT/edge computing, microservices, multi-agent systems, block chain, JSON scheme, 5G, Integration platform, ESB, AI and machine learning, AVM, PHM, Cloud computing, autonomous robot, AGV, and 3D printing.
- There is ongoing standards work that includes I4.0 Component and List of properties standards within IEC TC65.

5.5 Conclusion

The following tables summarize the capability gaps for service-oriented manufacturing systems and the technical solutions and the top prioritized action items. The items represent a focused set of requirements for the development of SOASM.
### Capability Gaps for SOASM

1. Reference model for SOASM  
2. Service capability modeling; description and integration language (for composition)  
3. Capacity and performance characterization and measurement, including aggregation  
4. Manufacturing service requests should indicate nonfunctional requirements: for example, response time, carbon emission, safety, and security  
5. How to define service interfaces – message modeling, API: manual vs automatic invocation  
6. Service registry and semantic modeling  
7. Service-oriented system verification and validation  
8. How to encapsulate the existing applications/functions in services

### Technical Solutions

1. Start with more use scenarios at different levels  
2. Start with activity models (e.g., ISA 95) and taxonomies (e.g., eCl@ss)  
3. Application context modeling  
4. Define list of properties of manufacturing systems  
5. Start with Web service interface standards for interface and registry definition and capture dynamic information later  
6. Learn the approach of real time bidding from IT industry (Google)  
7. Quality of Service Verification & Validation (QoS V&V) – refer to networking technology

**Tool decisions:**
1. Reduced-scale testbeds  
2. Cloud-based platform

### Priority Actions

1. Collect use scenarios at different levels  
2. Work with ISA 95, etc., on defining Level 2 and 4 activity models  
3. Survey existing taxonomy from eCl@ss and list of properties to support service modeling  
4. Standard service (common service types) agonistic to application  
5. Service type extended to vertical sectors  
6. How to quantify service capability - Data-driven capability quantification (extrapolation, transfer learning)
6 Smart Manufacturing Applications and Services Marketplaces

6.1 Overview

With the proliferation of devices that establish high degrees of connectivity, data collection, and data analysis capabilities, we can see “Smart Manufacturing Architectures” becoming popular. “Smart” has become a common term preceding everything that deals with advancements in the field. It is necessary and timely to think about how hardware (sensor and communication equipment and manufacturing equipment), modeling, analytics, and software will work together in a seamless manner and advance smart manufacturing. With the focus of “architecture” and “applications in the context of market places”, this workshop brings together academicians, industrial practitioners, and government representatives to address the foundational issues. We aim to bring together these experts from different regions (North America, Europe, Asia) and/or backgrounds (e.g., Industrial Internet, Industry 4.0, Intelligent Manufacturing Systems) who will present their (and their communities’) understanding of enabling architectures in a Smart Manufacturing scenario.

Modern manufacturing industry is investing in new technologies such as Internet of Things (IoT), big data analytics, cloud computing, and cybersecurity to cope with system complexity and dynamics, increase information visibility, improve production performance, and gain competitive advantage in the global market. This advancement is rapidly bringing the new generation of smart manufacturing, i.e., a new cyber-physical system tightly integrating the manufacturing enterprise in the physical world with the virtual enterprise in the cyber space and interfacing with society. It is increasingly a consensus that operational technology & information technology (OT/IT) integration through robust architectural guidance is an essential aspect of successfully implementing smart manufacturing in the manufacturing enterprise. Realizing the full potential of cyber-physical social systems depends to a great extent on the development of new methodologies in the Internet of Manufacturing Things (IoMT) for data-enabled engineering innovations and integrating it with dynamic social needs. Given the proliferation of manufacturing innovation institutes at the national level and each having its focus, it is important in the evolving context to clearly specify the architectural aspects of the future enterprises – starting from society needs to strategic decision-making of manufacturing organizations.

It is necessary for all players in the manufacturing domain from academia, government, and industry to clearly lay out the foundations of computing infrastructures for future smart manufacturing. Needs (social and industrial) keep changing. How can manufacturing organizations use these changes and resulting new requirements? How can these new requirements propagate through manufacturing organizations? To answer these questions, it is becoming increasingly clear that we need a robust architectural design. Is it enough to have the cloud, IoT, and analytics as services? Are there architectures that go beyond these (and if so, which ones and how do they differentiate themselves from one another’)? What will be applications in the context of marketplaces and where (at what level) are they placed within the architecture? What are the right questions to ask? What will be the direction of the right answers?

We aim to establish a clear roadmap of what a smart manufacturing architecture will look like, with a specific focus on

a. levels/perspectives (e.g., data-driven) in manufacturing and translating them into architecture levels,

b. models for capturing and processing data, modeling, and analytics.

Ultimately, we hope that this provides the architectural foundations for a future factory seamlessly interfacing with robots, machines, and humans. Aside from this objective, we hope to discuss the current landscape of enabling architectures for several of the popular (international) variations of Smart Manufacturing, namely, Industry 4.0, Smart Manufacturing, Industrial Internet, IIoT, Intelligent Manufacturing, CPS/CPPS, etc. We hope to achieve a better understanding of the differences in enabling architectures (if any), including the individual perspectives they are built upon (e.g., Data centric, Hardware centric, etc.).
6.2 Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>Introductions</td>
</tr>
<tr>
<td>9:15</td>
<td>Clean Energy Smart Manufacturing Innovation Institute (CESMII) Smart Manufacturing Marketplace Architecture (Craig Dory, CESMII / Rensselaer Polytechnic Institute)</td>
</tr>
<tr>
<td>9:45</td>
<td>Edge Computing Methods for Smart Manufacturing Apps (Sagar Kamarthi, Northeastern University)</td>
</tr>
<tr>
<td>10:15</td>
<td>Automated Planning-based SM applications (John Jung-Woon Yoo, Bradley University)</td>
</tr>
<tr>
<td>10:45</td>
<td>Decision Guidance Systems &amp; Service Networks: A marketplace to connect innovative product ideas with (SME) manufacturing capacity (Alex Brodsky, George Mason University)</td>
</tr>
<tr>
<td>11:15</td>
<td>Discussions</td>
</tr>
<tr>
<td>11:45</td>
<td>Lunch</td>
</tr>
<tr>
<td>13:00</td>
<td>Smart Sensors and their implementation in smart manufacturing (SM) systems (Satish Bukkapatnam, Texas A&amp;M)</td>
</tr>
<tr>
<td>13:30</td>
<td>Parallel Computing and Network Modeling for Efficient Condition-Monitoring Apps in SM Market Place (Hui Yang, Penn State University)</td>
</tr>
<tr>
<td>14:00</td>
<td>Holistic Approach to Machine Tool Data Analytics (Thorsten Wuest, West Virginia University)</td>
</tr>
<tr>
<td>14:30</td>
<td>Discussions</td>
</tr>
<tr>
<td>3:30</td>
<td>Session Ends</td>
</tr>
</tbody>
</table>

6.3 Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soundar Kumara</td>
<td>Penn State University</td>
</tr>
<tr>
<td>Thorsten Wuest</td>
<td>West Virginia University</td>
</tr>
<tr>
<td>Craig Dory</td>
<td>CESMII</td>
</tr>
<tr>
<td>Sagar Kamarthi</td>
<td>Northeastern University</td>
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<td>John Yoo</td>
<td>Bradley University</td>
</tr>
<tr>
<td>Alex Brodsky</td>
<td>George Mason University</td>
</tr>
<tr>
<td>Satish Bukkapatnam</td>
<td>Texas A&amp;M</td>
</tr>
<tr>
<td>Hui Yang</td>
<td>Penn State University</td>
</tr>
<tr>
<td>Thurston Sexton</td>
<td>NIST</td>
</tr>
</tbody>
</table>

6.4 Highlights

The session highlights included the following:
• One result is that in our session a data driven perspective is taken in almost all presentations. The Smart Manufacturing app examples were mainly focused on extracting and analyzing data, be it on the edge, in the cloud, or elsewhere.

• Three main themes were discussed across all contributions: Composable Applications, Different (architecture) Levels; and No Higher Level Insights. In the following, these three themes are elaborated in more detail.

• **Composable Applications** facilitate workflows and utilization of different levels of data analytics and manufacturing resources
  - New CESMII architecture was presented (a big step forward)
  - Apps in the marketplace included those published by 3rd party providers, users (or such), and marketplace/platform-integrated ones (e.g., visualization)
  - Possibility to compose workflows of various apps and provide those to others who face similar challenges

• **Different (Architecture) Levels** come into play when talking about apps in the smart manufacturing environment, machine vs system level, cloud vs. edge, etc.
  - Smart sensors using SM wrappers addressing some of the interoperability issues
  - System level: example - use power profile to compare manufacturing machine tools
  - Questions that arose included: What happens when analytics are performed on the edge and only the results are transferred in cloud - this basically reduces the ability for further in-depth analytics (which brings me to my next point)

• How can ‘black boxes’ in apps / analytics services be overcome? A heavily discussed challenge was how the current models often provide a result that is correct but does not provide any higher-level insights that improve understanding of the system
  - Another discussion on that topic circled around using decision guidance systems

### 6.5 Conclusion

In conclusion, the interest in and development of Smart Manufacturing Apps and Services Marketplaces continues to increase. This year marks an important step with the presentation of the CESMII marketplace architecture as a reference for the future development. Going forward, we envision this workshop moving its main focus from development aspects to analysis, comparison, and critique of existing marketplaces, as well as deep-dives into specific issues on theoretical and applied levels. These issues may include the effective and efficient composition of multiple apps and services, (semi-)automated negotiations, and collaborator identifications. It can be safely stated, that despite the fact that the first marketplaces are starting operation, there are several interesting research issues, theoretical and practical, that still deserve our attention.
7 Industrial Ontologies Foundry (IOF) - Creating Semantic Content for Industry

7.1 Overview

This session focused on the Industrial Ontologies Foundry (IOF), an emerging effort for converging and extending existing semantic representations from the industrial and manufacturing domains. The primary purpose of the IOF is to develop a collaborative framework and platform supporting development, submission, evaluation, validation, and sharing of ontologies for the industrial and manufacturing domains. In this way, knowledge can be captured in a common semantic form and shared to facilitate smart manufacturing and other industrial practices and resources along the lifecycle of a manufactured product.

This was the third workshop held for the IOF. After the first workshop, held at NIST in December 2016, a community of manufacturing end users, software vendors, and researchers formed to pursue the IOF idea. The resulting organization now has a charter, website, and an organizational structure including a Governance Board and Technical Oversight Board. A pilot effort (aka proof-of-concept) is also underway to explore a top-down approach to defining the top 20 notions identified through a survey of the membership. This effort will be used to test and evolve approaches to formalize manufacturing knowledge that will be canonized as principles and practices of the organization. The pilot effort has also identified various common-interest areas that are expected to lead to the formation of Domain Boards focused around manufacturing subdomains or groupings of related manufacturing notions.

The nascent state for the IOF provided the context for this third IOF workshop. However, the workshop was not a working session focused on making decisions, but rather was focused on exchange of information that could inform decisions and directions for the IOF going forward. Sessions in this workshop fell into the following categories:

- Use cases employing semantic technologies in industry
- Introductory summaries of related efforts and new participants
- Case studies that employed a top down approach to manufacturing ontology development
- A report from the Top-Down thread of the IOF community’s proof-of-concept
- Tools to support the IOF and uses of its content

7.2 Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30</td>
<td>Keynote – Model-Based for Manufacturing in Airbus (Fernando Mas, Airbus Senior Expert - remote)</td>
</tr>
<tr>
<td>9:10</td>
<td>Overview of IOF Session (Evan Wallace, NIST)</td>
</tr>
<tr>
<td>9:20</td>
<td>Standards for smart manufacturing: using ontologies to landscape standards into knowledge graphs (Irlan Grangel-González, Fraunhofer IAIS)</td>
</tr>
<tr>
<td>10:05</td>
<td>Use Case: End of Life Processing (Richard Sharpe, Loughborough University)</td>
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<tr>
<td>10:35</td>
<td>ST4SE - Semantic Technologies for Systems Engineering (Dr. Todd Schneider, Engineering Semantics)</td>
</tr>
<tr>
<td>10:45</td>
<td>Development of Ontology based decision support system for Manufacturing Process Planning (Dusan Sormaz [presenter], Professor, Arkopaual Sarkar, PhD Student; Department of Industrial and Systems Engineering Ohio University)</td>
</tr>
<tr>
<td>10:55</td>
<td>Towards a Unified Database for the Norwegian Manufacturing Research Laboratory (Oleksandr Semeniuta, Norwegian University of Science and Technology)</td>
</tr>
<tr>
<td>11:10</td>
<td>The Product Life Cycle Ontologies and the IOF: Cases, Lessons, and Best Practices (J. Neil Otte, Department of Philosophy, University at Buffalo (SUNY))</td>
</tr>
</tbody>
</table>
11:50 Using BFO to categorize and define IOF proof-of-concept terms (Top-down approach) (Hyunmin Cheong, Research Scientist, Autodesk)
12:30 Lunch
1:30 Modular Ontologies for Engineering Design and Decision Making (Thomas Hagedorn, UMass Amherst)
2:00 Using Ontology for Model-driven User Experience (Sam Chance, Managing Director of Solution Engineering, Cambridge Semantics)
2:20 Tools and Infrastructure for continuous integration: FIBO case study (Dean Allemang, Working Ontologist, LLC; EDM council - remote)
3:00 Mobi: A Shared Collaboration Environment for Semantic Content (Stephen Kahmann, Technical Lead, Special Programs, Inovex Corp.)
3:30 Session Closed

7.3 Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farhad Ameri</td>
<td>Texas State University</td>
</tr>
<tr>
<td>Sam Chance</td>
<td>Cambridge Semantics</td>
</tr>
<tr>
<td>Hyunmin Cheong</td>
<td>Autodesk</td>
</tr>
<tr>
<td>Tim Finin</td>
<td>University of Maryland, Baltimore County</td>
</tr>
<tr>
<td>Paul Goodall</td>
<td>Loughborough University</td>
</tr>
<tr>
<td>Michael Gruninger</td>
<td>University of Toronto</td>
</tr>
<tr>
<td>Mark Gryparis</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td>Thomas Hagedorn</td>
<td>UMass Amherst</td>
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<tr>
<td>Kevin Mark Himka</td>
<td>Boeing Company</td>
</tr>
<tr>
<td>Stephen Kahmann</td>
<td>iNovex Information Systems</td>
</tr>
<tr>
<td>Dimitris Kyritsis</td>
<td>EPFL</td>
</tr>
<tr>
<td>Pom Jin Lee</td>
<td>Korea Institute for Advancement of Technology</td>
</tr>
<tr>
<td>J. Neil Otte</td>
<td>University at Buffalo</td>
</tr>
<tr>
<td>Ian Phillips</td>
<td>Lockheed Martin</td>
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<tr>
<td>Todd Schneider</td>
<td>Engineering Semantics</td>
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<tr>
<td>Oleksandr Semeniuta</td>
<td>NTNU</td>
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<tr>
<td>Richard Sharpe</td>
<td>Loughborough University</td>
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<tr>
<td>Dr. Dusan Sormaz</td>
<td>Ohio University</td>
</tr>
<tr>
<td>Dr. Toshiya Teramae</td>
<td>Hitachi LTD.</td>
</tr>
<tr>
<td>Evan Wallace</td>
<td>NIST</td>
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<tr>
<td>Roy Whittenburg</td>
<td>MBD360 LLC</td>
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<tr>
<td>Jim Wilson</td>
<td>OAGi</td>
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</table>
7.4 Highlights

This session highlighted:

- areas of interest and requirements from industry such as mediation between models and services (e.g., from Airbus and Loughborough University),
- extensive prior work such as the Common Core and CHAMP ontologies that could be leveraged for IOF content,
- work ontologizing manufacturing standards that enable the agility of Industry 4.0,
- capabilities of tools available for creating, managing ontology content, and exploiting it for insight, and
- methods, successes, and challenges in managing parallel development and evolution of ontologies in FIBO, a similar effort to IOF for the financial sector.

Additionally, Neil Otte proposed adopting BFO as the upper ontology, the Common Core Ontologies (CCO) as Middle ontologies for IOF, and the product life cycle ontology as a starting point for mid-level ontologies. He also proposed adoption of a set of best practices from this experience. This workshop was not organized to make such decisions, so no action was taken on these proposals. The ontologies mentioned are available at: https://github.com/NCOR-US/CHAMP. His proposal is in Appendix B of this document.

7.5 Conclusion

Presentations and participation at this workshop indicated that there is significant industry interest in ontology-based solutions for managing the volume and variety of data in manufacturing industries (particularly in those involved in designing and building complex electromechanical products, such as the aerospace industry). While there is a great deal to do to create semantic models to support such needs, there are similar efforts that have already made this journey in other communities such as biology (OBO Foundry) and finance (FIBO). The IOF community can leverage what those other efforts have learned in terms of methodology, practices, and tooling to speed up our effort in the industrial space. Furthermore, there is a healthy subcommunity already working on ontologies for manufacturing and other engineering-intensive domains that has been participating in the IOF since the first workshop in December 2016. The next step for the IOF group is to hold a face-to-face meeting to decide its priorities, which methodology, practices, and tooling to adopt, and on what schedule. By the end of this workshop, IOF leadership had already begun planning such a meeting for mid-summer 2018.
8 Data Analytics

8.1 Overview

Enhancement of data analytics capabilities is the urgent key strategic issue for large corporations. Few organizations can make effective use of data analytics, while the majority is still figuring out the best approach to synthesize the big data to allow the C-suite to make better-informed decisions. Recently, artificial intelligence (AI) has become the primary goal of data analytics implementations; however, it is well established only in large and sophisticated firms that have support from both senior leaders and information technology systems. This session focused on both technical and interface obstacles associated with manufacturers using cloud-based, data-analytics services.

8.2 Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
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<tbody>
<tr>
<td>9:00</td>
<td>Introductions</td>
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<tr>
<td>9:15</td>
<td>Data Analytics: Transforming UPS for Today and Tomorrow</td>
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<tr>
<td>9:45</td>
<td>Discussion</td>
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<td>3:00</td>
<td>Session Ends</td>
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8.3 Participants

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<tr>
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<tr>
<td>Albert Jones</td>
<td>NIST</td>
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<tr>
<td>Wilawan Onkham</td>
<td>UPS</td>
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</table>

8.4 Highlights

There are several challenges for development and deployment of analytical schemes in manufacturing, such as using cloud-based, data-analytics (DA) services. For example, UPS collects massive data from its customers – information about approximately 16 million packages daily. In the vision of CEO David Abney, UPS wants to harness big data to support business decisions. The smart global logistics network initiative was developed as one of strategic investments for technology advancement. It is at higher levels of automation and integration than the current technology. However, the biggest challenge is to fill the gap between what UPS wants to be and what it currently has especially in terms of quality, nature, and dimension of data; computation time; and urgency of task. Four challenges of data analytics are illustrated below.

The first problem involves matching specific manufacturing problems to specific DA solution algorithms. For example, what kinds of manufacturing problems are best solved using neural networks and how can we choose an appropriate algorithm for the available data? One of alternative solutions is to develop a dynamic heuristic process to select the best algorithm for a particular data set using either model accuracy or error as criteria.

The second issue involves estimating uncertainties associated with using those algorithms, data quality, software implementations of the algorithms, and any exogenous factors impacting the results. Currently there is no standard nor measurement to indicate the level of data quality or cleanliness and, importantly, how to know when to stop cleaning or manipulating the data before ingesting it to a model-development process.
The third issue involves extending the existing predictive model markup language (PMML) to include standardized guidelines for helping manufacturers create the models and training data needed to use PMML. PMML is the leading standard for statistical and data-mining models. Currently, PMML is supported by over 20 vendors and organizations. With PMML, it is easy to develop a model on one system using one application and deploy the same model on another system using a completely different application. PMML provides a way for analytic applications to describe and exchange predictive models produced by data mining and machine-learning algorithms.

The fourth topic involves measuring the accuracy of data-analytics models in the real-world of manufacturing. Typically, the percentage of errors or R-square are common measurements of predictive models. These measurements are reasonable when there is enough of historical data to train and test the predictive model. In some business cases, we may have only a few weeks of historical data and the business requirement is to predict the future for the next weeks. It will be very difficult to have a validation period preventing model over-fitting problems and model accuracy may be below acceptable limits. Statistically, this predictive model cannot explain a trend or seasonality pattern of such data set. This means that it is impossible to build a completely error-free DA model. This is true regardless of (1) the amount, type, and quality of the input data and (2) the complexity of the manufacturing process. The ability to measure that model accuracy is critical. Indeed, we need knowledge and experience to come up with appropriate solutions.

8.5 Conclusion

In conclusion, advancing the data analytics capabilities is a critical course of action for organizations to gain market competitiveness. However, it is very difficult to judge what is an optimal approach. This issue also depends on the vision of senior leaders and flexibility of the organizational structure to prevent wasting money without adding any value to the organization or for its customers.
9 Summary

This document reported on the 2018 NIST/OAGi Workshop: Enabling Composable Service-Oriented Manufacturing Systems, which is fourth in a series of workshops begun in 2015 to foster a shared vision of a new Smart Manufacturing (SM) platform that will support Composable Service-Oriented Manufacturing (SOM) systems. The workshops explore the needed technical foundation for achieving the vision. The following are main findings from the workshop and next steps proposed for the workshop series.

9.1 Key Findings

9.1.1 Extensive New Technical Capabilities Are Needed for Composable SOM

Realizing the vision of Composable Service-Oriented Manufacturing (SOM) requires many advances in underlying technologies to build more capable systems-integration approaches. The focus of the workshop and the community is on (1) providing new reference model life-cycle management (RM LCM) capabilities and (2) using those capabilities to build required new technologies.

Each breakout session, within its respective area of interest, discussed advances in RM LCM capabilities for the new technologies. Common to the sessions’ differing perspectives is that all sessions focused on developing knowledge-based modeling approaches to achieve RM LCM methods. This focus is in line with developing needed capabilities to communicate and act on information in context-specific ways without failures in interpretation and without costly mediation help, re-interpretation, or manual intervention. These capabilities are then utilized to allow new models, methods, and tools to play a key role in enabling Composable SOM systems by supporting interoperable integration, search for and discovery of relevant manufacturing services, and configuration and reconfiguration of these services. In summary, the following is how the five breakout sessions help develop knowledge-model-based RM LCM capabilities to enable advances towards Composable SOM Systems:

- **Smart Manufacturing (SM) Model-Based Messaging Standards Development (MBMSD) Methods** provides knowledge-model-based specification for conveying customization and context information for manufacturing services within SOM Systems, which will be used to advance message standards life-cycle-management (MSLCM) capabilities.

- **Smart Manufacturing Systems Characterization (SMSC) Methods** develops knowledge-model-based characterizations of both the manufacturers’ requirements and the technologies’ capabilities, which will be used to support reasoning about the composability of these technologies within SM systems based on their interface designs.

- **Smart Manufacturing Reference Models and Architecture (SMRMA)** provides knowledge-model-based specifications for conveying information about data interchange, systems integration, and data fusion, enabling development of (1) a Smart Manufacturing Reference Architecture and (2) information standards and system interfaces, which are needed to allow disparate services/systems to exchange, understand, and exploit information flows.

- **Smart Manufacturing (SM) Apps and Services Marketplaces (SMASM)** explores knowledge-model-based definitions of multiple aspects of SOM systems, apps, and marketplaces, which will be used to support the identification and analysis of current technological and other challenges as well as requirements from the stakeholders for Composable SOM Systems.

- **Industrial Ontology Foundry** investigates new knowledge-model-based approaches to develop a collaborative framework and platform for submitting, validating, and sharing ontologies for the industrial and manufacturing domains. In this way, the new approaches will be used to facilitate smart manufacturing practices and resources in Composable SOM Systems.
• Data Analytics (DA) explores both technical and interface obstacles associated with manufacturers using cloud-based, data-analytics (DA) services. The issues explored are knowledge-intensive and include matching specific manufacturing problems to specific DA solution algorithms, and estimating uncertainties associated with using these algorithms.

9.1.2 R&D Road-mapping is a Needed Resource in Developing Composable SOM

This workshop report provides descriptions of the goals, missing capabilities, proposed technology characteristics, and action items in six working areas, based on the participants’ discussions in the corresponding breakout sessions. This material is intended to enable a future R&D road-mapping effort. Future workshops may refresh the material as needed.

The road-mapping material can be used by the stakeholder community to plan and direct development of new technologies and by SDOs to develop the standards needed to integrate those technologies into Composable Service-Oriented Manufacturing systems. Stakeholders are expected to make use of this and future workshop reports to update and align their R&D programs relevant to Composable Service-Oriented Manufacturing systems.

9.2 Next Steps: R&D Projects to Enable Industrial Impacts

As in the previous year’s workshop, it is recognized that the ultimate governance goal of the workshop series is to support the community to drive specific R&D projects to contribute to the vision of Composable SOM apps/services and systems. The many topics discussed in the workshop represent a wealth of information that can be used to prioritize and initiate new R&D projects in industry, academia, and government R&D programs.

Future workshops are expected to provide a vehicle to help the community drive towards this governance goal. It is hoped that future events such as the workshop series will enhance the maturity and enable execution of collaborative R&D efforts with high probability of success. Along with the R&D focus, future workshops need to pay close attention to potential impact of the R&D efforts.
Appendix A – Key Terms

- **Composable Service-Oriented Manufacturing (SOM)** – High-value SOM approaches with the core capability to efficiently search for and discover relevant manufacturing services, integrate services in interoperable ways, and configure and re-configure these services to meet changing requirements.

- **Knowledge-based Modeling** – Modeling of information, functions, processes, organizations, and other aspects of man-made systems that allows capture and sharing of both structured and unstructured information as well as specifications of manufacturing systems, processes, and products in computer-processable forms. The computer-processable representations capture information, know-how, guidance, heuristics, and standards that enable reasoning necessary for realizing Composable SOM systems.

- **Reference Models Life-Cycle Management (RM LCM) Methods** – A critical part required by new technologies to achieve Composable SOM. The methods address the activities ranging from creation, to adaptation, to use of reference models. These methods play essential roles in achieving precise management of reference semantics for the domain and reliable interpretation of context-specific domain information required by Composable SOM Systems. Techniques used in the LCM methods need to support high-level abstractions, separation of concerns, and loose coupling. They may use declarative approaches, including information- and knowledge-based models, rule-based systems, and taxonomy- or ontology-based systems.

- **Service-Oriented Manufacturing (SOM) Systems** – Manufacturing systems paradigm influenced by the service-oriented views of computing and information systems where manufacturing capabilities and resources are provided as services within a distributed, open ecosystem of service providers and consumers who use these services in assembling their systems.

- **Smart Manufacturing Systems (SMS)** – New generation of advanced manufacturing systems enabled by the convergence of information and communication technologies with emerging physical technologies to influence more efficient, automated, programmable, and flexible forms of manufacturing that meet changing consumer demands, market conditions, and supply chain capacities.

- **SOM Life-Cycle Management (LCM) Capabilities** – Capabilities of SOM Systems that include both (1) the SOM services life-cycle management (including requirements analysis, design, analysis, provisioning, deployment, discovery, use, and decommissioning of services) and (2) the SOM ecosystems life-cycle management (including SOM services composition, design of SOM ecosystems operations, and, optimization of SOM ecosystem services execution).
The IOF ought to officially adopt Basic Formal Ontology as an upper-level ontology and the Common Core Ontologies as mid-level ontologies. Then, the IOF should begin with the Product Life Cycle Ontologies, and revise, extend, and replace them as needed.

Common Core Ontologies (CCO) is a suite of mid-level ontologies, including ontologies of:

- Agents
- Artifacts
- Currency Units
- Events
- Extended Relations
- Geospatial
- Information Entities
- Modality
- Qualities
- Time
- Units of Measure

BFO-conformant, good documentation, widely-used, more polished than many OBO Foundry ontologies, and relevant to the domain of industry.

The Product Life Cycle (PLC) Ontologies is a suite of mid-level ontologies, including ontologies of:

- Commercial Entities
- Design
- Manufacturing Processes
- Maintenance
- Product Life Cycle
- Testing Processes
- Machines and Tools

Pros: BFO and CCO-conformant, and appropriate to the scope of the IOF. Presently, there is work underway to add to it an ontology for material properties.
Cons: Still a work in progress

CONSIDERATIONS IN FAVOR OF THE ABOVE

- BFO and the CCO are widely used, well-documented, and highly successful ontologies.
- Adopting BFO will bring in the resources of the National Center for Ontological Research.
- The PLC ontologies will provide users with clear examples of how their ontologies may be re-factored to be conformant with BFO.
- The governance of the PLC ontologies is available starting June 1, 2018.
- BFO has been approved as ISO/IEC standard 21838-2
- BFO is available in both OWL and CL (CLIF and FOL) formats

Resources:
All ontologies discussed here, along with these slides and this handout, are available at: https://github.com/NCOR-US/CHAMP. The National Center for Ontological Research website and wiki are here: https://ubwp.buffalo.edu/ncor/ and http://ncorwiki.buffalo.edu/index.php/Main_Page

Side Two: Cases, Lessons, and Best Practices

1. The True Path Rule applies to asserted classes only. Use defined classes for convenience and to aid in conforming to the rule.

   Ex. Product = ‘Artifact and bearer of some Product Role.’
2. When building reference ontologies, avoid creating many relations that double the semantic work being done by classes. Example:

Bad: ‘Product has_product_function some Product Function.’
Better: ‘Product bearer_of some Function.’

3. Processes should be represented by classes, not relations.

4. Every class should receive an Aristotelian, or genus-species form, definition to be placed in a class annotation, and a separate annotation should list the term editor who is responsible for creating it.

5. If necessary, allow cheats and short cuts in application ontologies. Reference ontologies require representing what is true of reality, not what is expedient.

6. Creating hierarchies for artifact types is hard. Don’t forget to represent artifact functions, artifact manufacturers, past uses of artifacts belonging to the same product line, etc. This will aid querying for artifacts even in the absence of a well-built taxonomy of artifact types.

7. A service is a process. When you sign a service agreement, you don’t buy a service. You buy the claim on someone else to provide the service, and the seller acquires an obligation to provide that service upon request. Both the claim and the obligation may be represented with roles.

8. The completeness of your ontology doesn’t rest with whether or not someone’s preferred term is available in it, but rather, with whether or not your ontology can express the same meaning in an alternative vocabulary.

9. In class labels, use prefixes and sortal noun phrases. Examples:

Bad: Water
Good: Portion of Water
Bad: Work
Good: Process of Work

10. Certain terms like ‘color’ can refer both to a disposition (e.g. the power to induce others to have a certain qualitative experience) and the quality that is the base of the disposition (e.g. the surface grain structure responsible for reflecting light away from an object). When necessary, represent both

11. Never confuse information with the entities the information is about. ‘5 centimeters’ is not a length; rather, it is a measurement that is about a length
Appendix C – Presentation Materials from Day 1 of the Workshop

This appendix contains presentation material from the first day of the workshop approved for publication by the authors.
Manufacturing USA and DMDII

NIST/GOAIG Workshop: Enabling Composable Service-Oriented Manufacturing Systems
April 23, 2018

Mike Molnar
Advanced Manufacturing National Program Office
An interagency team building partnerships with U.S. Industry and Academia

Agenda

- Manufacturing USA Overview
- How an Institute Works – DMDII
- Network Today / Closure

Manufacturing USA

President’s Council of Advisors on Science and Technology
Advanced Manufacturing Partnership – 2011-2012
Advanced Manufacturing Partnership 2.0 – 2013-2014
Revitalize American Manufacturing and Innovation Act
118 bipartisan co-sponsors signed into law December 16, 2014

National Network for Manufacturing Innovation
Enhancing American Competitiveness by
- Manufacturing technology
- Education & Workforce Development

PCAST: Manufacturing USA Institutes
Addressing the “Scale-up” Gap

Focus: address market failure of insufficient industry R&D in the “missing middle” or “industrial commons” to de-risk promising new technologies

Approach: bring private sector investment back to the gap

The Institute Design
Creating the space for Industry & Academia to collaborate

Institute Framework Design published January 2013

Academia

University & National Labs
Community Colleges

Industry

Large Manufacturing companies
Small & Medium enterprises
Start-ups

Government

Federal
State & Local
Economic Dev. Org.

Shared Use Facility

Institute for Manufacturing Innovation
Prototypes Lab/Shop
Research Faculty
Computer Lab

National Network of Institutes
Institute Example: Digital Manufacturing and Design Integration

UI LABS/DMDII Facility, Chicago IL
GRAND OPENING MAY 2015

Agency sponsor: DOD
Startup funding: $70M public, $110M co-investment
44,000 square feet - digital manufacturing lab, instructional and collaboration space

1) Each Institute has a clear mission based on a critical Industry need

DMDII exists to transform American manufacturing competitiveness by accelerating the development and adoption of digital technology across the manufacturing enterprise

2) Each Institute creates value for industry participation and funding

- Workshops
  Topic-focused sessions where partners engage in solution oriented discussions to drive projects and investments

- Factory Floor
  Creating an experiential manufacturing environment to demo, test & prove a wide variety of DM&D technologies

- PROJECTS
  Applying the DMDII workshop and technical outcomes into real world applications

3) Each Institute creates an effective collaboration space for pre-competitive applied R&D

Future Factory Platform
A neutral space for experimentation, testing, development and validation of next generation Digital Manufacturing solutions

Digital Capability Center
A dedicated training environment to teach core Digital Manufacturing concepts

4) Each Institute is operated by an industry-led consortium

- Aerospace & defense
- Industrial equipment
- CPG
- Chemical & agriculture
- Automotive
- Pharma & specialty products
- High tech & telecom
- Small to mid-sized manufacturers
- High growth startups + technology providers
- Universities + community colleges
- McKinsey & Company

5) Federal start-up funding for each Institute must catalyze at least 100% co-investment

Funding

$70,000,000 Digital Manufacturing Innovation Institute
$165,000,000 Other Commitments

DMDII is funded by a five year $70,000,000 cooperative agreement from the federal government and leverages >$180,000,000 in other commitments.
6) Each Institute works on the industry priorities and big challenges only solvable by collaboration

**Theme: Supply chain management**
- **Objective:**
  - Solve the skills gap on education and workforce for their technology space.
  - Convert previous MBD/MBE/Digital Twin work with new project calls, workshops and pilots to practice with pragmatic solutions that are inspired by real-world constraints represented through pilots and member feedback.
  - Focus is cyber-hardening small-to-medium-sized manufacturers (SMMs), which represent 90%+ of U.S. manufactured GDP.

7) Each Institute manages a balanced portfolio of real projects for industry

**Portfolio Management**
- **Focus: Cyber Security**
  - **Key Activities:**
    - Pilot: Day in the life of CAD
    - Workshop: Sensor ROI & Marketplace
    - Pilot: Factory digital twin in member operations
    - Workshop/project: Real-time CAD feedback
    - Workshop/project: Sensor ROI & Marketplace
    - Pilot: Supply chain design and digital twin
    - Workshop/playbook: Pragmatic model-based-definition (simulation)

**Institute: DMDII**
- **INSTITUTE:**
  - **Pilot:** Cyber Security Hub: Work with DoD to establish
  - **SW Tool:** SMM cyber assessment & mitigation
  - **Workshop/pilot:** Blockchain for supply chain use cases
  - **Workshop/project:** Real-time CAD feedback
  - **Pilot:** Supply chain design and digital twin
  - **Workshop/playbook:** Pragmatic model-based-definition (simulation)
  - **Pilot:** Supply chain design and digital twin
  - **Workshop/project:** Real-time CAD feedback
  - **Pilot:** Supply chain design and digital twin
  - **Workshop/playbook:** Pragmatic model-based-definition (simulation)

8) Each Institute addresses the skills gap on education and workforce skills for their technology space

**Online Courses**
- **Goals:**
  - Workforce
  - Jobs Taxonomy
  - Train the Trainer
  - STEM Education

**WFD**
- **Focus:**
  - Digital Manufacturing
  - Industry 4.0
  - Additive Manufacturing
  - Flexible Hybrid Electronics
  - Implantable Medical Devices
  - Advanced Manufacturing
  - Critical Infrastructure Protection
  - Bio/pharmaceuticals
  - Defense
  - Energy
  - Environment
  - Information Technology
  - Life Sciences
  - Manufacturing
  - Materials
  - Modeling & Simulation
  - Nanotechnology
  - Packaging
  - Transportation
  - Validation & Verification

**Future of WFD at DMDII**
- **Expected Mix:**
  - Experiential, in-person training
  - Scalable online services

**Agenda**
- **Manufacturing USA Overview**
- **How an Institute Works – DMDII**
- **Network Today / Closure**

**Today a Network of Fourteen Institutes**
- **Institute:**
  - DMDII
  - AIM
  - Made in America
  - BRAEIC
  - Rapid/Made in America
  - GBCI
  - LIFT
  - CAMI
  - AMF

**In Years 3 or 4 of Federal Funding**
- **New Institutes:**
  - AMF
  - Made in America
  - BRAEIC
  - Rapid/Made in America
  - GBCI
  - LIFT
  - CAMI
  - AMF

**2012** | **2013** | **2014** | **2015** | **2016** | **2017**
Unique Institute Charters spanning a range of technologies

Electronics

Materials

Bio-Manufacturing

Energy Usage / Environmental Impact

Digital Automation

Together we are Securing America’s Future

Making an Impact

- 14 innovation institutes develop new manufacturing techniques
  - decrease manufacturing costs; scale up; share equipment; develop standards; ensure cybersecurity for manufacturing; provide access to expertise; ensure industry leadership
- ~300 collaborative R&D projects
- 200,000 people trained in advanced manufacturing
- 1 billion federal investment matched by over $2 billion non-federal funds

Visit: www.ManufacturingUSA.com
Follow: @mfgUSA

Thank you!

Visit: www.ManufacturingUSA.com
Follow: @mfgUSA

All tables, figures, and photos in this document were produced by the Advanced Manufacturing National Program Office Interagency Working Team, unless otherwise noted.
But before we begin-

So what is smart manufacturing?
To put simply, create new, additional jobs in the U.S.

Smart way to improve efficiency, productivity –
energy, material, and competitiveness

But I could not resist an alphabetical soup
SM = IoT+CPS+AI (ML)
Manufacturing is vital for US economy

Advanced manufacturing has a multiplier effect on job creation and can counteract declining domestic productivity growth and increasing foreign competition.

Manufacturing contributed $2.18 trillion to the US economy. For every $1.00 spent in manufacturing, another $1.81 is added to the economy.

Taken alone, manufacturing in the United States would be the ninth-largest economy in the world.

But there is US R&D Investment Gap

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<tr>
<td>NEW PRODUCTS</td>
<td>~2.5B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INCREMENTAL INNOVATION</td>
<td>~2.5B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMPROVED PRODUCTS</td>
<td>~2.5B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

But there are barriers according to McKinsey Analysis

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

- Difficulty in coordinating actions across different organizational units
- Uncertainty about industry 4.0 applications
- Concerns about cybersecurity
- Lack of a clear business case that justifies investments in the underlying IT architecture

For more information, please visit Manufacturing USA Program and Process.
There is a slow and uneven progress in capturing value from data

The answers you get are:

- resulting knowledge might walk out the door, as employees join other firms or start their own,
- you can acquire firms who have the needed technology.

• If everyone followed that logic, however, there’d be little innovation to walk out the door or to acquire!

• Fortunately, neither of these concerns is warranted according to Sarah Williamson, why companies, investors, and the nation will be better off if companies make long-term investments in R&D.

There’s No Good Alternative to Investing in R&D, Anne Marie Knott, HBR, April 17, 2018

Sarah Williamson is the CEO of FCLTGlobal

But we have great opportunity for US Competitiveness and global leadership

Two major opportunities

1) Smart Manufacturing Contribution to Energy Productivity Goal 2030

Two major opportunities

2) Economic Impacts of technology infrastructure to support Smart Manufacturing

OUTLINE

• EERE/AMO and Manufacturing USA Overview
• Current Barriers and Opportunities
• Goals and focus of CESMII
• Smart Manufacturing
  – Data Analytics, Reference Model and Testbed
  – CESMII Roadmap
• Potential Collaboration Topics
• Q&A
**CESMII Vision:** Smart Manufacturing is manufacturing in 2030

**MISSION**
Radically accelerate the development and adoption of advanced sensors, controls, platforms, and models for U.S. manufacturing through integrated, industry-led Smart Manufacturing (SM) technical, business, and educational methodologies.

**GOALS**
- 15% improvement in energy efficiency in first-of-a-kind demonstrations at manufacturing plants or major processes within 5 years
- 50% reduction in cost and time to deploy SM in existing processes within 5 years
- Significant industry adoption of SM technology within 5 years
- Sustainable portfolio of business, technology, research and development, and workforce development activities that directly replaces initial Federal funding within 6 years
- 50% improvement in energy productivity within 10 years

**OBJECTIVES**
To enhance U.S. manufacturing productivity, global competitiveness, and reinvestment, leading to significantly:
- Increased productivity
- Improved energy efficiency
- Cost reduction for installation

---

**Let us look at CESMII Focus**

**CESMII Roadmap**
- Data Analytics, Reference Model and Testbed
- CESMII Roadmap

**Technology (Operations & Information)**
- Process Technology
- Sensor technologies
- Data Analytics and SPC

**Research & Development**
- Process modeling & measurements
- Testbed requirements w/ ASCMM
- Testbed Characteristics

**WFD**
- Workforce Development
- Certification
- Learning factories

---

**Let us look at CESMII Focus – Workforce Development and Education**

---

**OUTLINE**
- EERE/AMO and Manufacturing USA Overview
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- Q&A

---

**What is Data Analytics?**

- **Descriptive**
  - What happened?
  - Describes historical data
  - Helps understand how things are performing
- **Diagnostic**
  - Why did it happen?
  - Statistics and sensitivity analysis
- **Predictive**
  - What will happen?
- **Prescriptive**
  - How can we make it happen?
- **Cognitive**
  - What to do, why, and how?

The purpose of computing (analytics) is insight, not numbers. - Richard Hamming

---

**So what are the Goals and Focus of the Institute?**

- Increased productivity
- Improved energy efficiency
- Cost reduction for installation

- **Problem**
  - How much energy efficiency can be achieved?
  - What is the current state of the art?
  - What is the new knowledge discovery, innovation?

- **Solutions**
  - Open and interoperable platform plug and play connectivity integration and customization

---

Dr. Sudarsan Rachuri AMO/EERE/DOE

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[Image references]
We need Smart Data

Without data you are just another person with an opinion. Just because you can measure everything doesn’t mean that you should.

– W. Edwards Deming

We need a good Model-based Advanced Analytics

Predict and Control
Product Quality

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

Dr. Sudarsan Rachuri
AMO/EERE/DOE

We need a Testbed Framework

Levels* | Data | Motivation | Function | Network | Time | People
---|---|---|---|---|---|---
Machine Level | Why | How | Where | When | Who
Process Level | | | | | |
Shop floor level | | | | | |
Plant Level | | | | | |
Extended Enterprise Level (Including supply network) | | | | | |
Deployed Testbed | | | | | |

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

Smart Manufacturing Reference Architecture

We need a Testbed Framework

Levels* | Data | Motivation | Function | Network | Time | People
---|---|---|---|---|---|---
Machine Level | Why | How | Where | When | Who
Process Level | | | | | |
Shop floor level | | | | | |
Plant Level | | | | | |
Extended Enterprise Level (Including supply network) | | | | | |
Deployed Testbed | | | | | |

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

What are the Layers of Smart Manufacturing Technologies?

Based on the Testbed Framework let us look at OT&IT Integration

IT | OT | PCO | MBEA | Data Analytics | MPC
---|---|---|---|---|---
Sensors | M2M | HPC | | | & Security
Petroleum refining | | | | | & Security
Chemicals | | | | | & Security
Metals manufacturing | | | | | & Security
Food and beverage | | | | | & Security
Glass | | | | | & Security
Pulp and paper | | | | | & Security
Defense and Aerospace | | | | | & Security
Discrete manufacturing | | | | | & Security
Microelectronics | | | | | & Security
Additive Manufacturing | | | | | & Security
Other Applications | | | | | & Security

Dr. Sudarsan Rachuri
AMO/EERE/DOE

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AMO/EERE/DOE

Dr. Sudarsan Rachuri
AMO/EERE/DOE

Dr. Sudarsan Rachuri
AMO/EERE/DOE
What is the strategy for Testbed for Smart Manufacturing?

Let us look at similar efforts

Industrial Internet Reference Architecture

Let us look at similar efforts

Outcomes of CESMII

OutLINE

- EERE/AMO and Manufacturing USA Overview
- Current Barriers and Opportunities
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  - Data Analytics, Reference Model and Testbed
  - CESMII Roadmap
- Potential Collaboration Topics
- Q&A
CESMII Roadmap Objectives

- Start up the Institute and continue to build the world’s best SM network, providing:
  - Objective information on SM technologies
  - R&D portfolio that only an Institute can address
  - Consultation, assessment, and SM Platform access
  - Cross-industry information and studies
  - Training
- Cross-link CESMII Regional Manufacturing Centers (RMCs)
- Launch first call for CESMII projects
- Set up for CESMII Roadmapping 2018–2022 process

DEFINING CESMII’s R&D PORTFOLIO

- Facilitate implementation of new manufacturing solutions and OT-IT integration
- Accelerate early-stage R&D in ways no company or industry can do alone.

The CESMII R&D Portfolio will simultaneously address knowledge gaps and advance innovation in SM technology, processes, and workforce.

Key Items for Successful Projects and Proposals

A. Define the actual manufacturing problem
B. Identify R&D Challenges, Opportunities, Knowledge Gaps
C. Explain Quantitative and qualitative methods to be used
D. Discuss Data management methods
E. Explain the Use of Machine learning in a Smart-Paradigm
F. Identify Sensor-computing interfaces
G. Use of Smart Manufacturing Reference Architecture & Platform
H. Describe Data-driven and Hybrid models
I. Explain Model V&V UQ
J. Identify Knowledge gaps, Reusable Components for Testbeds

CESMII ROADMAP STRUCTURE

The CESMII Roadmap: 2017–2018 includes the following content:
- Strategic Objectives — the desired outcomes of CESMII activity
- R&D Portfolio — priority needs for collaborative R&D projects, studies, and assessments (not include for Workforce Development)
- Near-Term Action Plan — a timeline of activities for the next year

OUTLINE

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  - CESMII Roadmap
- Potential Collaboration Topics
- Q&A
Some Opportunities

https://www.astm.org/SSMS

Q&A ???

Sudarsan.Rachuri@hq.doe.gov

Advanced Manufacturing Office (AMO) Multi-Year Program Plan For Fiscal Years 2017 Through 2021


Dr. Sudarsan Rachuri
AMO/EERE/DOE
2018 The NIST & OAGI Workshop, Gaithersburg

Smart Factory Promotion and Standardization in Korea
(Results, Reference Model, Future)

2018. 4. 23
Dong-Hag Choi
Smart Manufacturing
National Standards Coordinator

Contents
1. World Crisis and Industry 4.0
2. Manufacturing Innovation Strategy
3. Smart Factory Promotion
4. Smart Factory Cluster Projects
5. Standardization in Korea

Current Crisis in the World

Industrie 4.0 & Trends in the World

Industrie 4.0 & Trends in Korea

Manufacturing Innovation Strategy in Korea

- SMEs participate in the smart factory program voluntarily
- Government and Companies collaborate supporting SME to go SMART
- Government Guides Three-Track Approaches

Increased needs of Implementation Technologies for multinational corporations and middle standing firms in Korea
Increasing ICT Industry (IoS, IIoT, CPPS, Cloud, Big Data, 3D Printing, AR/VR/MR, AI) for Smart Factories in Korea
System Implementation Promotion

Korea Smart Factory Foundation (KOSF)

Transformation & Diffusion
- Smart Factory Transformation for SMEs
- Diffusion of Idea and Technology

Technology Planning
- Adoption of Advanced Solutions and Technologies (A-ICBM+)
  * A-ICBM: AI, IoT, Cloud, Big Data, Mobile

Result of Smart Factory Promotion

Average of the result from 2,800 Companies ('16E)

Case 1 – MES for Vacuum Heat Treatment

Case 2 – MES for Vehicle Parts Ass’y

Saehan Vacuum Heat Treatment Co
(http://heatreatment.co.kr/):
1. First year saving of electricity cost exceeded initial investment ($50,000)
2. Reduction of defects by 67%

SSMMS SHVHT Smart Manufacturing Management System

Cases 2 – MES for Vehicle Parts Ass’y

Welding Parts
- T-Type
- Square Type
- Ring Type
- Stud Bolt
Cases 2 - MES for Vehicle Parts Ass'y

OUTPUT
Frontec, Inc. (http://e-frontec.co.kr/)

Revenue
Profit
Defect
New jobs

Case 3,4
3. MES for Food Production
4. MES for Plastic Work

Case 5,6
5. MES for Electronic Parts Ass'y
6. MES for Machinery Parts Ass'y

Case 7,8
7. MES for Precision Manufacturing
8. MES for Surface Treatment

Case 9,10
9. MES for Machinery Parts Ass'y
10. MES for Chemical Plant

Case 11,12
11. Cloud MES for Precision Mfg.
12. CPS for Machinery Parts Ass'y
Case 13,14

13. ERP for Plastic Work
14. PLM for Mold

Case 15,16

15. (주)연우 - Cosmetic
www.yonwoo.kr
16. 디스글로벌 - Inspection
www.dsglobal.biz

Case 17, 18

17. 미크로기술 Inspection
www.mirtech.com
18. 새질물처리 Heat treatment
www.heatreatment.co.kr

Case 19,20

19. 에이엔텍 Semicon. EQ.
www.mirtech.com
20. 유남정기, Copper Parts
www.yncco.com

Case 21,22

21. 트럼프라스트, Plumb
www.plumbfast.co.kr
22. 한국나노텍, Painting
www.paintb.modoo.at

Smart solution providers behind the scene

South Korea, important future suppliers of Industrie 4.0 Solutions
Smart solution providers behind the scene(1)

MES Solution (DABOM - MES)
- It integrates 4M (Man, Machine, Material, Method) information of production resources with M2M technology of wired and wireless sensor.
- Applies Web service standard MES application technology to enable real-time central management of multiple plants scattered around the global.

Smart solution providers behind the scene(2)

CPS Solution (UDM Platform - CPS)
- This CPS platform could support strategic decision making solution by connecting all the information on vertically & horizontally integrated horizons verifying, sharing and analyzing cyber-physical models & data.

Smart solution providers behind the scene(3)

APS Solution (MOZART - APS)
- Integrated planning and scheduling solutions for smart operation management of semiconductor and display industries.
- Achievement: Keeping the level of accuracy by more than 95% and reducing the cycle time by 20 to 30%.

Cooperating Organizations for KOSF

Representative Smart Factory

Objective of Smart Factory Cluster
- Developing the advanced smart factory reference model for leading the smart innovation in the industrial complex.

Six Projects
- Developing the Representative Smart Factory
  - Best practice system for SMEs which high-tech Smart manufacturing technologies are concentrated.
- Developing the Demo Smart Factory
  - Test-Bed center for smart manufacturing technology and system.
- Smart Communication Infra
  - Big-data center for manufacturing information analysis, cloud service for factories, IoT standard
- Smart Factory Propagation in Banwool/Shwa industrial complex
- Learning Program for Factory Workers
- Tour Program of Representative and Demo Smart Factory
Use Case - Standardization for SHINSHINSA (on going)

[Issue]
Press Factories have same problem

[Before]
6 persons, 15 sec/each, 2,000 pcs/day

[After]
1 person, 10 sec/each, 2,000 pcs/day

- LG Electronics
- Purchasing Team
- Mutual Growth Team
- Institute of Production and Technology
- SHINSHINSA
- POSTECH
- Partners #1, #2, #3
- National Standards Coordinator KATS

Smart Manufacturing NSC KATS

KATS
(Korea Agency for Technology and Standards)
Promote Industrial Competitiveness
Improve Standard of Living
Intelligent Infrastructure

Thanks

Dong-Hag Choi
Smart Manufacturing
National Standards Coordinator
Korea Agency for Technology and Standards

nsc.smart.factory@gmail.com
+82-10-8822-9344
The Importance of Quality and the Visions of Industry 4.1

Industry 4.0 values productivity, but overlooked the importance of quality

- Industry 4.0 significantly improved productivity by focusing on productivity lines, but quality remains an overlooked aspect. This has made it difficult for factories to achieve the goal of zero defects. The key reason is the lack of affordable and practical online real-time total inspection systems.

Samsung Note 7 battery defects causing over 24 billion USD of loss

- The Samsung Note 7 smartphone battery production process, while demanding high productivity from the production line, resulted in the quality of the products being relatively low. According to estimations from Bloomberg, Samsung lost 2 billion USD in revenue and the market value of its stock depreciated by over 22 billion USD.

Zero Defects and the Visions of Industry 4.1

- From the example mentioned above, we can understand that it is important not to overlook the quality of products while pursuing productivity. By integrating technologies such as Automatic Virtual Metrology (AVM), Intelligent Predictive Maintenance (IPM), Intelligent Yield Management (IYM), and Advanced Manufacturing Cloud of Things (AMCoT) into the industry 4.0 platform, the goal of zero defects can be achieved. This is defined as "Industry 4.1" by professor Fan-Tien Cheng. The intelligent manufacturing system developed by iMRC can realize the visions of Industry 4.1.

Intelligent Manufacturing System Framework

- iMRC's focus is on equipping the production lines of various industries with comprehensive intelligent services based on the cloud, enabling various kinds of intelligent manufacturing services on the cloud, and promoting "Single-Machine Intelligence" and "Fab-Wide Intelligence".

iMRC Mission Statement

- Improving production efficiency and yield rate is a worldwide goal
- To stay competitive in a globalizing world economy, applying information and communication technology (ICT) to improve manufacturing efficiency and quality is the common practice of the manufacturing industry around the world. Germany's Industry 4.0 is one of the examples.

- Smart Machinery Industry Program
  - Taiwan Government promotes "Smart Machinery Industry Program" to provide more intelligent manufacturing options.

- iMRC's mission is to achieve the goal of manufacturing zero-defect products.
  - To cooperate with the "Smart Machinery Industry Program," iMRC integrates the researches from interdisciplinary and inter-university collaboration, providing various kinds of intelligent manufacturing services on the cloud based on the Advanced Manufacturing Cloud of Things (AMCoT) framework so as to develop a comprehensive intelligent manufacturing cloud service system. iMRC is dedicated to equipping the production lines of various industries with the intelligent manufacturing capabilities, so that the manufacturers are able to produce Zero-Defect products as well as high efficiency and high flexibility machine tools.
  - (Intelligent manufacturing capabilities includes single-machine intelligence, production-line intelligence, and fab-wide intelligence.)
Missions of iMRC

- Our Intelligent Manufacturing Research Center is dedicated to assist various Manufacturing Industries to realize the visions of Industry 4.1.

- Phase 1: Accomplishing the goal of having zero defects of all the deliverables.
- Phase 2: Accomplishing the goal of having zero defects of all the products.
  (Big Data Analytics & Continuous Improvement)

Abstract

- Virtual Metrology (VM) is a method to conjecture manufacturing quality of a process tool based on data sensed from the process tool when physical metrology is not available to achieve the goal of total inspection.
- In other words, VM can turn the offline sampling inspection with metrology delay into online and real-time total inspection.
- The Automatic Virtual Metrology (AVM) system developed by our team has been applied to high-tech industries such as semiconductor, TFT-LCD, and solar-cell industries. Recently, the AVM system has also been deployed in the traditional machine-tool and aerospace industries such as Wheel Manufacturing Automation and Engine-Case Manufacturing.

Industrial Requirements for Total Inspection

- To save the costs, the industries adopt sampling inspection to conduct quality monitoring in the present stage, but this cannot achieve comprehensive quality control.
- To economically reach the goal of total inspection, the development of virtual metrology (VM) technology is required.
VM Definition

Virtual Metrology (VM) for Machine Tools

- VM can convert sampling inspections with metrology delay into real-time and on-line total inspection.

AVM Demonstrations

Live Demo of AVM for CNC Precision Machining
(At the 2012 Taiwan International Machine Tool Exhibition)

AVM Demo for CNC Precision Machining
(October 20, 2015 at ITRI)

AVM Demo for Engine-Case Manufacturing
(April 14, 2016 at AIDC)

AVM Demo for Cordless-Grease-Gun Manufacturing
(December 26, 2017 at FFG)

AVM Demo for Stretch PET Blow Molding Machine
(January 18, 2018 at Chumpower)

AVM Demo for CD of Photo Process
(February 1, 2018 at ASE)

Live Demo of AVM for CNC Precision Machining
(At the 2012 Taiwan International Machine Tool Exhibition)

- Video showing the precision machining on cellphone backplanes.
- GUI displaying real-time and online VM values of straightness 2.

AVM Demo for Standard-Workpiece Machining
(October 20, 2015 at ITRI)

- Step 1: Flatness
- Step 2: Straightness
- Step 3: Roundness
- Step 4: Angularity

Applying AVM to Standard-Workpiece Machining
(At the 2012 Taiwan International Machine Tool Exhibition)

- Scan QR-Code to read ID
- Put workpiece into CNC
- Grab workpiece

Live Demo of AVM for CNC Precision Machining
(At the 2012 Taiwan International Machine Tool Exhibition)

- The CNC tool was located in a machine tool factory in Taichung
- The GUI was shown at the Exhibition Hall in Taipei
Introduction to AVM Technology

Automatic Virtual Metrology (AVM) Scheme

Benefits of Implementing AVM

Companies or Organizations that have technology transferred and/or deployed AVM related Patents or Technologies

- Semiconductor Industry: TSMC (台積電), UMC (聯電), ASE (日月光)
- TFT-LCD Industry: AUO (友達), Innolux (群創), CPT (彩晶)
- Photovoltaic Industry: Motech (茂迪)
- Machine Tool Industry: FEMCO (莎美), (FFG)
- Aerospace Industry: AIDC (漢翔)
- Stretch Blow Molding Machine Industry: Chum Power (錦寶)
- Carbon Fiber Industry: Formosa Plastics Cooperation (台塑)
- Organizations: ITRI (工研院) (Machine Tool Technology Center) & Big Data Technology Center, MIRDC (僑大中心)
Advanced Manufacturing Cloud of Things (AMCoT)

Bumping Process Data Types

- Bumping process goes through the above production steps and will generate various types of data in the final yield rate inspection, and these data range from per second (e.g., tool log) to per week (e.g., yield inspection):
  - Different raw material data
  - Tool data (such as tool log: when to change components, or when to stop the tool, etc.)
  - Production data (such as process, maintenance, alarms, recipe, etc.)
  - Metrology data and defect data
  - Final yield inspection data

Advanced Manufacturing Cloud of Things (AMCoT)

Cyber-Physical Agent (CPA)
An IoT Device
Features of CPA

- Data Collection and Communication
  - Data Collection from all the physical objects is the fundamental feature of CPA.
  - Horizontal & Vertical Communications for integrations among physical objects, cyber systems, and human operators can enable reporting and decision making of CPS.
- Identification
  - All physical objects in WIPs should be uniquely identifiable.
  - CPA should know where the object is and what the object does at any time.
- Smart Applications
  - Various Smart Applications can be implemented as pluggable application modules and plugged into CPA.

Cloud-based Intelligent Yield Management (IYM) System

Intelligent Yield Management (IYM) System Framework

Yield and Cost Changes in Product Development Cycle

- Yields (blue line) will gradually rise up in the ramp-up phase, and then keep steady in the mass-production phase. On the contrary, product cost (red line) will decrease as the phases proceed.
- Company's competitiveness would be effectively enhanced if the blue/red solid lines could be improved into their corresponding segmented lines.

Process Flow of TFT-LCD Manufacturing

- The TFT-LCD manufacturing flow consists of four processes: TFT, CF (color filter), LCD, and LCM (liquid crystal module).
KSA Scheme (2/2)

- Input data of the KSA scheme can be sorted into three types:
  - Production Information
  - Defect
  - Final Inspection

- Production information includes: 1. Production route \( (X_a) \), 2. Process data \( (X_b) \), and 3. In-line metrology values which may contain real metrology \( (y) \) or Virtual Metrology \( (\hat{y}) \) values.

AMCoT for Smart Machinery

Machinery Cloud (機械雲)

Applying AVM to the Total Inspection of Wheel Machining Automation (WMA)

Application Diagram of AMCoT
Integrating WMA’s Vender and Customers into AMCoT

AMCoT Application Scenarios

Server-based – AVM & IPM Deployments
Server-based AVM, AVM DB, IPM, and IPM DB are deployed respectively onto two ADVANTECH’s EIS IPC.

Cloud-based – AVM & IPM Deployments
Four virtual machines including AVM, AVM DB, IPM, and IPM DB are deployed onto the hicloud.

Intelligent Machinery Cloud (智慧機械雲)
Smart Factory: Manufacturing Execution Optimization

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UNIVERSITY OF WISCONSIN-MADISON
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APRIL 23, 2018

Outline
- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Consumable software in Manufacturing

---

Shop-floor Management
- Transition from “knee-jerk” manual spreadsheet scheduling
- No validation to schedule changes
- 15 mins spent per operation to change formatting and calculations

---

Flow-Shop Real-time Optimization
- Loss of capacity by 10-15%

---

ERP Summary
- ERP got the numbers right
- Timing related decisions are almost useless
- Why?

---

Execution is not optimized
MES: Manufacturing Execution Systems

Planning | MRP/ERP
Execution | MES
Control | Controls

Planning and scheduling is based on MRP or APS technologies. Keep tracking time related activities.

Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Consumable software in Manufacturing

Manufacturing Execution Optimization

- A set of digital tools for enterprise system analysis, design, planning, scheduling, optimization, and improvement (based on Nested Partitions optimization framework)
- Highly configurable & scalable
- Full visibility to production outcomes
- Provide a common platform within Factory for information sharing and exchange
- Supports data-driven decision making in real time

Benefits of MEO

- Greatly improve on-time delivery rate
- Reduce MCT (Manufacturing Critical-Path Time) significantly
- Maximization of facility capacity
- Reduced Overhead count
- Be flexible to changing circumstances and know the impacts ahead of time

MEO Architecture

- Supply Chain Optimizer
- Outscoring Management
- Control & Monitoring
- IT-Optimization

- Planning Optimizer
- Sales Order Management
- Purchasing Management
- Work Order Management
- Data Analytics

- Scheduling Optimizer
- SO-A
- SO-J
- SO-H
- SO-F
- SO-P
- SO-C

- Feedback & Coordination
- Feedback
- Coordination
- Reports
- Visualization
Scheduling Modules

Job Shop
- Little item repetition, no BOM
- Focus on machine scheduling

Assembly
- Labor-dependent Operation Duration
- Simultaneous Operations
- Various precedence constraints

Specialized
- Heat treatment
- Fabrication
- Paint
- Service

Planning Coordination

- Released Schedule used as starting point (link with scheduling)
- Plans remaining Released Work Orders
- Plans Unreleased Work Orders
- Determines release and completion date
- Balances utilizations and due date performance by simulating releases, available hours, or earliest start dates

Simulation Optimization Problems

Production Control

- Uses information from ERP
  - FG inventory, WIP inventory w/ released schedule
  - raw inventory w/ released plan
- Assigns supply to demand
- Determines if Sales Order Due Dates can be met
- Minimizes MCT (Manufacturing Critical-Path Time)
  - Total time required to deliver final products
  - Identifying critical Work Orders (shifting)

Scheduling-Planning-Control

- Start from shop-floor: the source of variability
- Link local areas together to create coordination
- Bottom-up visibility to the impact on top-level demand
- Top-down prediction to results and control over top-level demand
- Response to changes and disturbances in real-time

Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Consumable software in Manufacturing

Case Study
Every one who is related to production communicates on the MEO platform.

Comment from the User

- “The utilization of the MEO is driving us to improve our discipline and causing a culture change.”

Real-time Simulation Optimization

Save 8-10%!

Outline

- Introduction
- Manufacturing Execution Optimization
- A Case Study
- Consumable software in Manufacturing

HISTORY

LEGACY MONOLITHS
One system does everything
Custom-built

ISOLATED MODULES
Collection of systems
Function-specific systems
Isolated

MICRO SERVICES
Function-specific services
Integrated
custom front end

Micro-services encapsulate niche experience and knowledge allowing customers to avoid reinvention and focus on customization within their organization.
Nested API
- Using nested layers comprised of solvers and simulation engines
- Decentralized but real-time coordinated with each functional entity
- Deploy sophisticated technology in an accessible format
- Focus on utilizing capabilities instead of building capabilities

Cyber-Physical Production Systems

Thank You!
Standard-based Semantic Integration, Past, Present, and Future
Composable Service-Oriented Manufacturing Systems Workshop
Serm Kulvatunyou, Ph.D.
Systems Integration Division
National Institute of Standards and Technology, USA
Scott Nieman
Land O’Lakes
April 23, 2018

Objective
• A perspective on history
• R&D activities we are engaging
• Future directions

HISTORY OF INTEGRATIONS

Stone Age (pre-Internet)

<table>
<thead>
<tr>
<th>Data Exchange Standards</th>
<th>Forms of Specifications</th>
<th>Exchange Formats</th>
</tr>
</thead>
<tbody>
<tr>
<td>X12 / EDIFACT</td>
<td>Data Dictionary, Text or Word documents, SEF</td>
<td>Tagged, Text file with varying delimiters, enumerated code lists</td>
</tr>
<tr>
<td>STEP</td>
<td>EXPRESS</td>
<td>STEP file exchange format, SDM</td>
</tr>
</tbody>
</table>

Technology Highlights

- Transfer technologies
  - File Import/Export, EDI VAN, Email, ETL, CORBA
- Storage technologies
  - File-based DB, RDBMS

Pain Point: low EDI adoption => Open EDI

Ref: ISO/IEC 14462
Bronze Age (Public Internet)

<table>
<thead>
<tr>
<th>Data Exchange Standards</th>
<th>Forms of Specifications</th>
<th>Exchange Formats</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEP</td>
<td>EXPRESS</td>
<td>EXPRESS-XML</td>
</tr>
<tr>
<td>OAGIS</td>
<td>DTO, XML Schema</td>
<td>XML, JSON</td>
</tr>
<tr>
<td>MIT-Connect</td>
<td>XML Schema</td>
<td>XML</td>
</tr>
<tr>
<td>OPC-UA</td>
<td>XML Schema</td>
<td>Binary, XML</td>
</tr>
<tr>
<td>ISO 15926</td>
<td>XML Schema, OWL</td>
<td>XML, OWL/RDF, JSON-LD</td>
</tr>
</tbody>
</table>

Technology Highlights

Transfer technologies: Message-oriented Middleware, EDIINT with AS1 and AS2, RMI-IIOP, Web Services (SOAP, WSDL, BPEL, ebXML), Enterprise Service Bus (ESB), REST (Swagger, ODATA).

Storage technologies: NoSQL

Pain Point: Need better Business Requirements

How do we provide context to the data?

Iron Age (Past Few Years and Forward)

<table>
<thead>
<tr>
<th>Data Exchange Standards</th>
<th>Forms of Specifications</th>
<th>Exchange Formats</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEP</td>
<td>SysML =&gt; EXPRESS, OWL, XML Schema, etc.</td>
<td>EXPRESS, XML, OWL/RDF</td>
</tr>
<tr>
<td>OAGIS</td>
<td>CCTS RDB =&gt; XML Schema, JSON Schema, OWL, etc.</td>
<td>XML, JSON, RDF, JSON-LD, Protobuf etc.</td>
</tr>
<tr>
<td>OPC-UA</td>
<td>UML =&gt; XML Schema, OWL, etc.</td>
<td>XML, RDF, JSON-LD, etc.</td>
</tr>
<tr>
<td>IOF</td>
<td>OWL</td>
<td>OWL/RDF</td>
</tr>
</tbody>
</table>

Technology Highlights

Transfer technologies: Cloud-based integration tools, Data Streaming Protocol, Swagger and ODATA for REST.

Storage technologies: Graph DBs, Relational-to-Graph (Ontology-Based Data Access)

Analysis of Business Process Context

OAGIS Model-Based Vision
What is OAGIS?
- Open Applications Group Integration Specifications (OAGIS)
- Since 1994
- 100+ Business Objects
- 1100+ Messages (BOD)

Approach: Syntax Independent Standard
- UN/CEFACT Core Component Specification: Meta-model
- OAGIS in RDBMS

Approach: Message Profiling based on Business Context
- UN/CEFACT Core Component Specification: Contextualization

Example

Result: NIST/OAGi Semantic Refinement Tool (SRT)
Functionality: Business Context Management

Functionality: Object Profiling

Functionality: Profiled Object Life Cycle Management

Functionality: Expression Generation

Functionality: New Standard Life Cycle Management

Core Component (Standard) Management

Roadmap

- JSON Schema, REST API
- Automatic profiled object upgrade
- Semantic-based search
- Multi-tenant
- Standard evolution
  - Standards usage harmonization
- Release & change management
- Integration with the business process management
An increase in regulations and compliance costs are pushing organizations to find new ways to optimize their operations.

### Regulatory Compliance Costs per Employee per Year

<table>
<thead>
<tr>
<th>President</th>
<th>From to Office</th>
<th>Total Major Changes</th>
<th>Average Major Change Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinton</td>
<td>1993-2001</td>
<td>61</td>
<td>1</td>
</tr>
<tr>
<td>Bush</td>
<td>2001-2008</td>
<td>55</td>
<td>7</td>
</tr>
<tr>
<td>Obama</td>
<td>2009-2013</td>
<td>62*</td>
<td>18*</td>
</tr>
</tbody>
</table>

The introduction of emerging technologies coupled with organizations looking for new ways to optimize their operations is introducing a complex landscape with many questions on where to start and how to operationalize the solutions.

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With a surge in tools and resource to help

- **MBE Capability Index**
- **ASME MBE Standards**
- **AGILE Development**
- **ISO Standards**
- **MTConnect**
- **SysML**
- **PLM/ERP/MES**
- **QIF**

---

Multiple technology shockwaves are impacting the manufacturing sector simultaneously

- **Digital human behavior**
- **Artificial intelligence (AI)**
- **Internet of Things (IoT)**
- **Robotics**
- **Augmented reality & virtual reality**
- **Additive manufacturing**

---

Harmonization of digital assessment tools is needed to accelerate the adoption of digital technologies within the industrial base and Department of Defense.

<table>
<thead>
<tr>
<th>Assessment Title</th>
<th>Purpose</th>
<th>Assessment Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Capabilities Assessment</td>
<td>Provides an organization’s digital view and additional capabilities required to be a completely digitally enabled learning</td>
<td>MGIC</td>
</tr>
<tr>
<td>MBE Capability Maturity Model</td>
<td>Enhances the level of an organization’s capability to be in a critical and competitive manufacturing</td>
<td>MEGU Innovation</td>
</tr>
<tr>
<td>Model-Based Enterprise (MBE) Capability Index</td>
<td>Identifies essential tools that, when implemented, would enhance or improve manufacturing performance</td>
<td>[Stop, Start, Accelerate]</td>
</tr>
<tr>
<td>Digital Enterprise Maturity Assessment</td>
<td>Creates an integrated cloud-based digital infrastructure at a high level of assessment criteria; impact on productivity, decision-making, innovation, learning culture, and enterprise collaboration</td>
<td>Boeing</td>
</tr>
</tbody>
</table>

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Manufacturers want to make sense of the digital noise
DMDII lead breakout session: Workshop Objectives

- The **objective** of this workshop is to:
  1. Review and gather feedback on **current and developing assessment tools** and the driving organizations behind the development and facilitation of the assessments
  2. Identify users of the assessments and define end-user objectives of the tools to refine and **inform digital assessment harmonization road mapping efforts**
  3. Identify requirements of the digital assessment harmonization output (e.g. digital taxonomy of organizations + assessments, interactive web-based tool, etc.)
  4. These objectives will be achieved through a series of interactive discussions and presentations

Thank you!!

Kym Wehrle
Director of Operations, DMDI
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Roy Whittenburg
President, MB360
rwhittenburg@mb360.com
IOF’s Primary Goal

The IOF’s primary goal is to create a suite of open and principles-based ontologies, from which other domain-dependent or application ontologies can be derived in a modular fashion, remaining non-proprietary and non-implementation-specific, so they can be reused in any number of industrial domains or manufacturing specializations.

Other IOF Goals

• Provide principles and best practices by which quality ontologies can be developed that will support interoperability for industrial domains
• Institute a governance mechanism to maintain and promulgate the goals and principles
• Provide an organizational framework and governance processes that ensure conformance to principles and best practices for development, sharing, maintenance, evolution, and documentation of IOF ontologies

Just Getting Started

• First meeting December 2016
• About 70 current participants
• Governance Board established and working
• Technical Oversight Board established and working
• Top-Down Working Group established and working

Governance Board Members

• Barry Smith, SUNY Buffalo
• Fernando Mas, Airbus
• Nicola Guarino, The National Research Council (Italy)
• Serm Kulvatunyou, NIST
• Chris Will, Dassault
• Michael Gruninger, University of Toronto
• Jim Wilson, OAGi

Governance Board Activities

• IOF Membership Policies and Procedures: nearly compete
• IOF Working Group Policies and Procedures: just getting started
• IOF Legal Establishment: starting soon
  • Funding
  • Secretariat services
  • Marketing and communications
Website

http://IndustrialOntologies.org

redirects to
https://sites.google.com/view/IndustrialOntologies

Join

Industrial Ontologies Foundry (IOF)

Join

IOF Participation Request

First name and Last name *
Your answer

Organization *
Your answer

Email address of the current IOF participant who invited you *
Your answer

Specific interests in IOF
Your answer