Engineering Laboratory: Manufacturing Programs

Thomas Hedberg, Jr., Ph.D., P.E.

Systems Integration Division, Engineering Laboratory

National Institute of Standards and Technology

Presented to the *Model-Based Enterprise Summit 2019*

4 April 2019

The Engineering Laboratory…

…promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology for engineered systems in ways that enhance economic security and improve quality of life.

Engineering Laboratory Goals

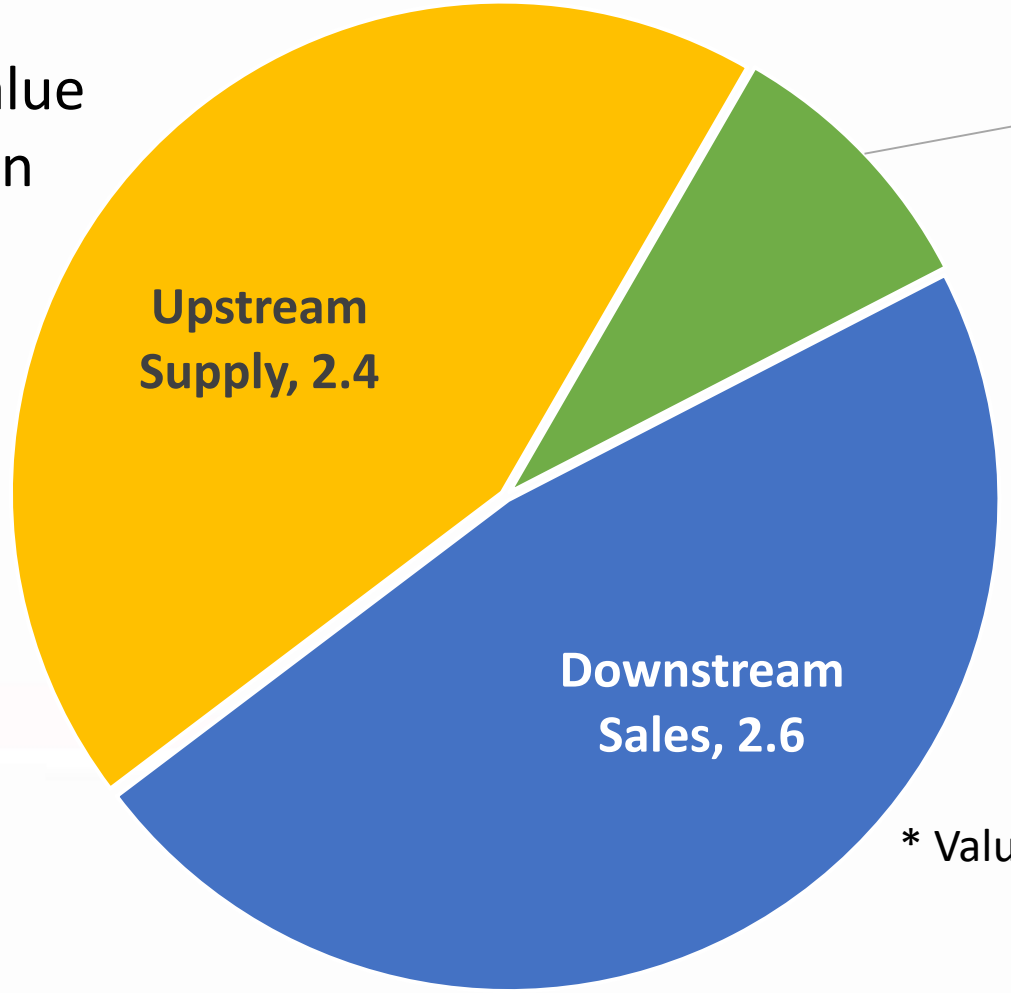
- Disaster-Resilient Buildings, Infrastructure, and Communities
- Cyber-Physical Systems
- Smart Manufacturing
- Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

Smart Manufacturing: the synthesis of advanced manufacturing capabilities and digital technologies to produce highly customizable products faster, cheaper, better, and greener

- Internet of Things/Ubiquitous Sensing
- Big data & advanced analytics
- Cloud computing
- Broadband communications, wireless
- Mobile computing/apps
- Security technologies
- Advances in additive processes/3D printing
- Advances in robotics
- Model-based enterprise
- Cyber-physical systems engineering
- Advances in materials

Manufacturing is ⅓ of the U.S. Economy

Total Manufacturing Value Chain of ~$5.5 Trillion



* Values are in Trillion USD ($)

MAPI Foundation. (2017, Accessed: 2017-08-21). Myth-Busting American Manufacturing. Retrieved from http://www.webcitation.org/6t5IoctUk

Moylan, S., & Rudnitsky, R. (2017). *Manufacturing USA: 2016 Annual Report*. Retrieved from Advanced Manufacturing National Program Office, National Institute of Standards and Technology, Gaithersburg MD: http://www.webcitation.org/6vYibCk9D.

Manufacturing Multiplier Effect

Value Add

$3.60 of value-add in the economy for every $1 of manufacturing value

Jobs

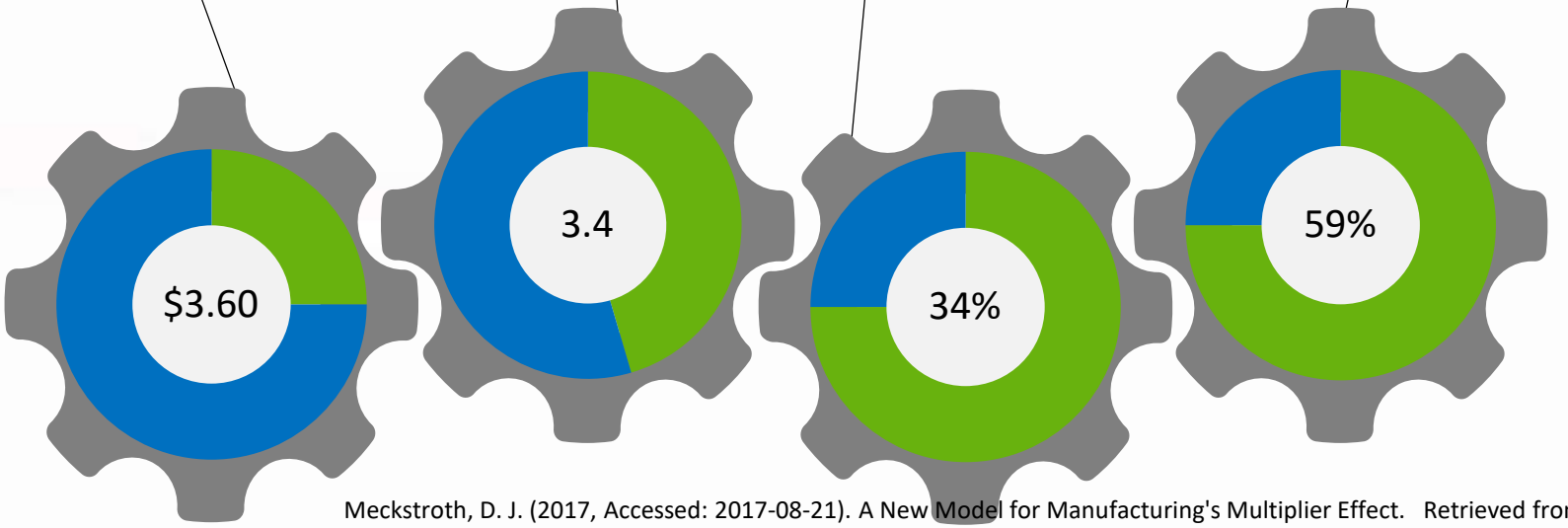
For each FTE manufacturing job, 3.4 FTE jobs are created in non-manufacturing sectors

U.S. GDP

Manufacturing final demand accounts for 34% of U.S. GDP

Exports

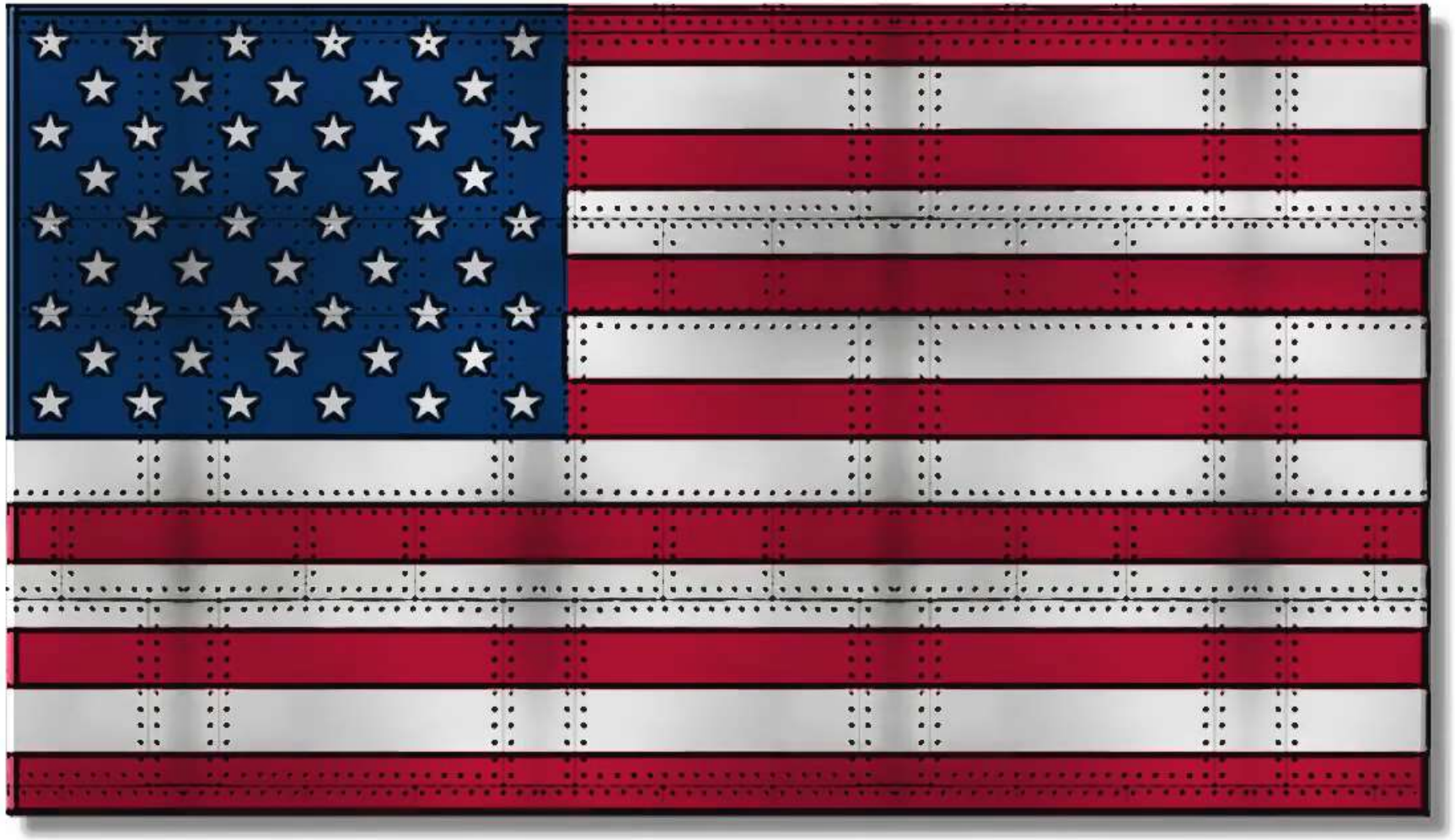
59% of Manufacturing demand is attributed to exports



Meckstroth, D. J. (2017, Accessed: 2017-08-21). A New Model for Manufacturing's Multiplier Effect. Retrieved from http://www.webcitation.org/6t5Iw6KtP

Giffi, C., Rodriguez, M. D., & Mondal, S. (2017). *A look ahead: How modern manufacturers can create positive perceptions with the US public*. Retrieved from Washington DC: http://www.webcitation.org/6t5Jrgh83

Productivity Growth



MAPI Foundation. (2015, Accessed: 2017-08-21). Facts About Modern Manufacturing. Retrieved from http://www.webcitation.org/6t5JUs9ye

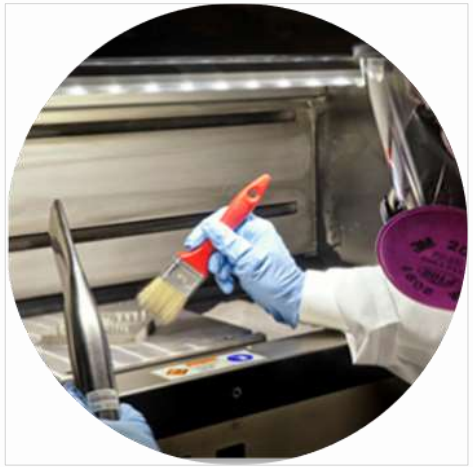
OBJECTIVE: Enable the next generation of innovative and competitive manufacturing

- Safely increase the versatility, autonomy, and rapid re-tasking of intelligent robots and automation technologies
- Enable real-time monitoring, control, and performance optimization of systems in the factories of small, medium, and large companies
- Enable rapid, agile, and cost-effective production of complex, first-to-market products through advanced manufacturing processes and equipment
- Facilitate integration of information systems used in complex manufacturing networks to improve product and process performance.

Smart Manufacturing, FY19 to FY23

Enabling Disruptive Process Technologies:

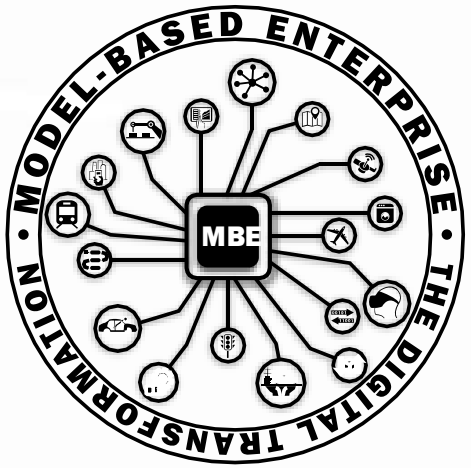
Additive Manufacturing



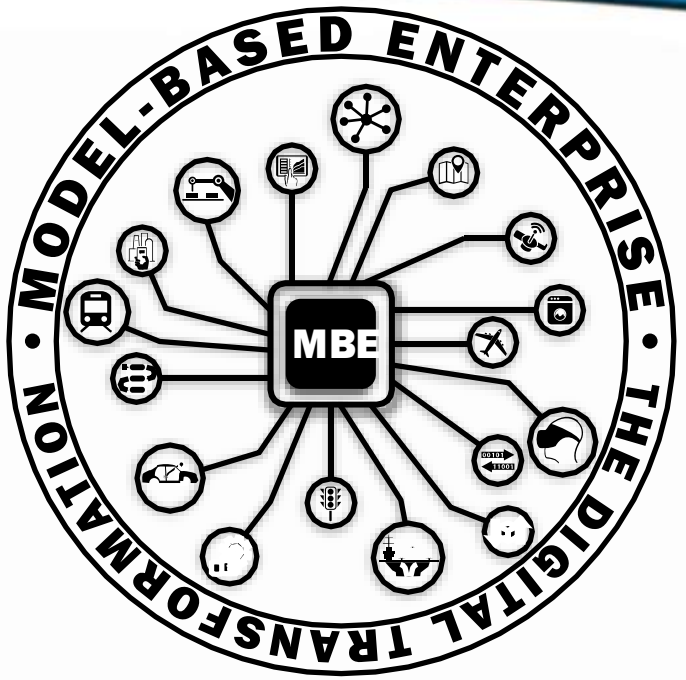
Robotic Systems

Enabling System Level Technologies:

Trustworthy Systems



Model-Based Enterprise

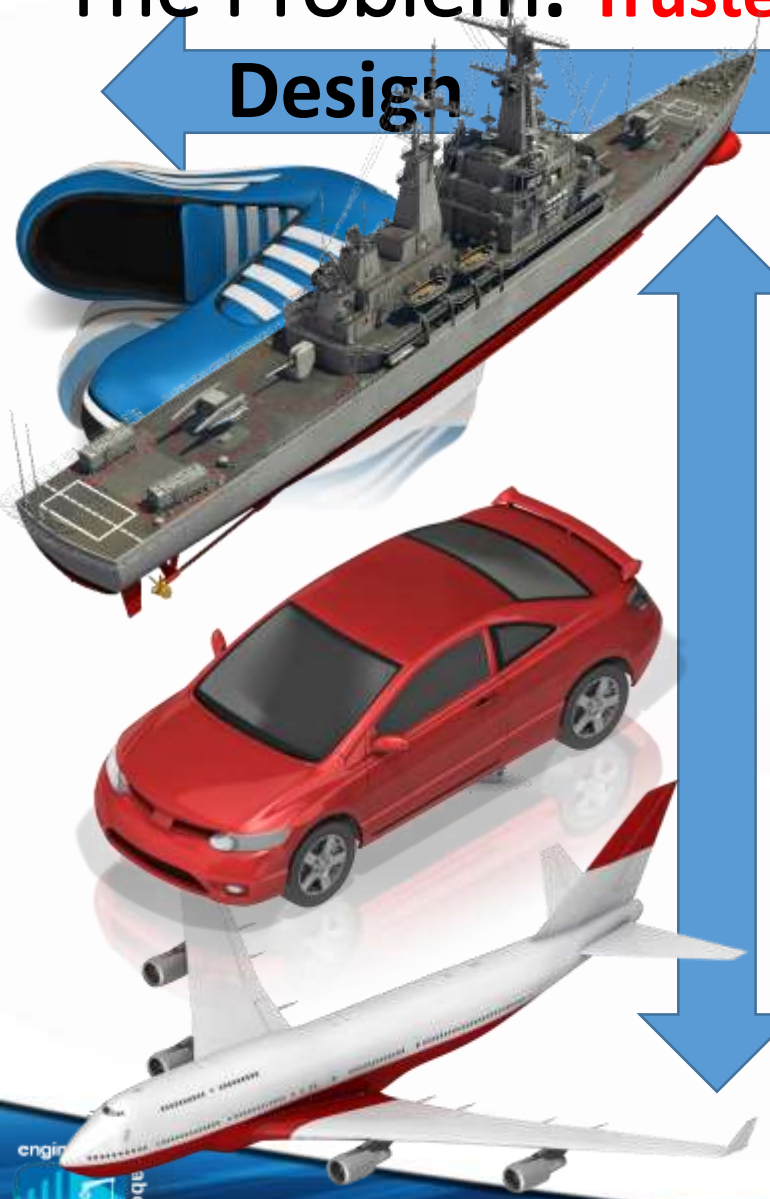


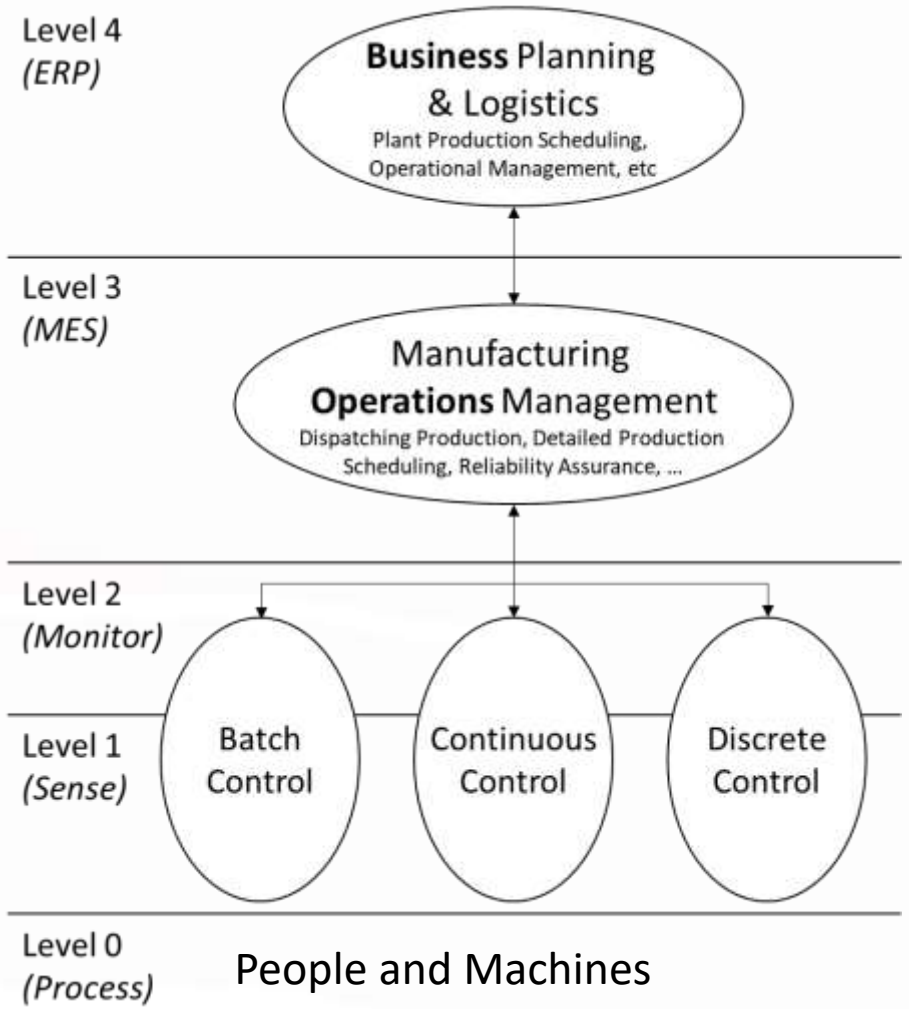
Model-Based Enterprise Program

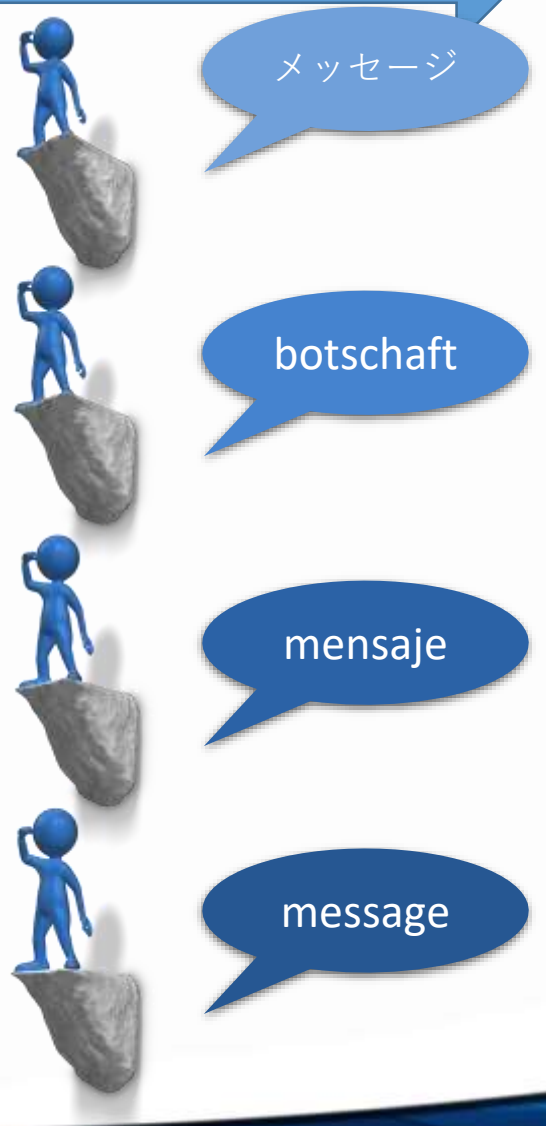
The Model-Based Enterprise (MBE) Program will develop and deploy advances in standards, test methods, and measurement science that enable manufacturers to integrate system, service, product, process, and logistics models across the manufacturing enterprise.

The Problem: Trusted Decision Making in Distributed Environments

Design → **Manufacturing** → **Sustainment**







Why?

- Decentralized manufacturing:
  OEMs = system integrators, SMEs = disconnected

- Change in demand:
  varying lot sizes, make it next door, on-demand ordering

- Wants and needs for agility and flexibility:
  rapid reconfiguration of products and manufacturing systems (e.g., shop floors)

1. Gallaher, M. P., Oliver, Z. T., Rieth, K. T., and O'Connor, A. C., 2016. Economic analysis of technology infrastructure needs for advanced manufacturing: Smart manufacturing. Report NIST GCR 16-007, RTI International.
2. Quan, T. and Williams, K., Product Variety, Across-Market Demand Heterogeneity, and the Value of Online Retail (November 17, 2016). Cowles Foundation Discussion Paper No. 2054. DOI: 10.2139/ssrn.2871513
3. Quan, T. and Williams, K., Product Variety, Across-Market Demand Heterogeneity, and the Value of Online Retail (June 26, 2017). Cowles Foundation Discussion Paper No. 2054R. DOI: 10.2139/ssrn.2993236

Opportunities

- Manufacturing and sustainment operations needs tools for figuring out what capabilities and capacities are located where
- Distributing complexity simplifies the problems [1], but must also be trusted and secure
- Increased opportunities for MFGaaS help SMEs –> $57 Million Annual Opportunity in simply better sensing and monitoring [2]

1. Mocker, M., Weill, P., & Woerner, S. (2014). Revisiting Complexity in the Digital Age. *MIT Sloan Management Review*. Retrieved from https://sloanreview.mit.edu/article/revisiting-complexity-in-the-digital-age/
2. Anderson, G. (2016). *The Economic Impact of Technology Infrastructure for Smart Manufacturing* (NIST Economic Analysis Briefs 4). Retrieved from Gaithersburg MD: http://nvlpubs.nist.gov/nistpubs/eab/NIST.EAB.4.pdf

Don’t listen to just me…

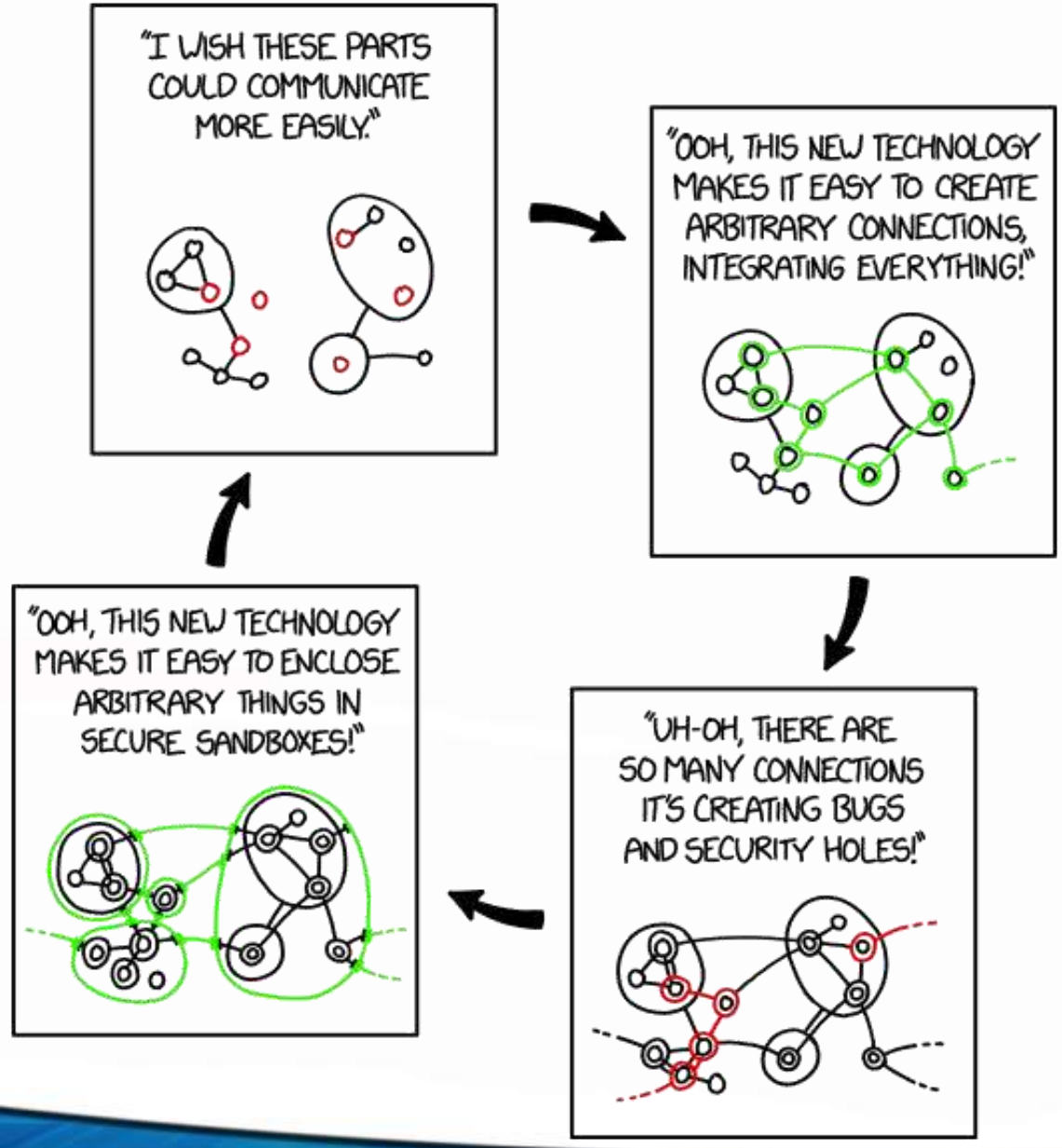
- The National Security Strategy includes producing parts and systems with healthy and secure supply chains supported by a skilled U.S. workforce as essential to the Nation’s manufacturing readiness

- U.S. DoD says digital transformation will address challenges associated with complexity, uncertainty, and rapid change in deploying and using systems

- Deloitte and McKinsey recommend using a holistic and systematic analysis in making decisions on how and where to best deploy and maintain technologies and capabilities

The Connection Paradox

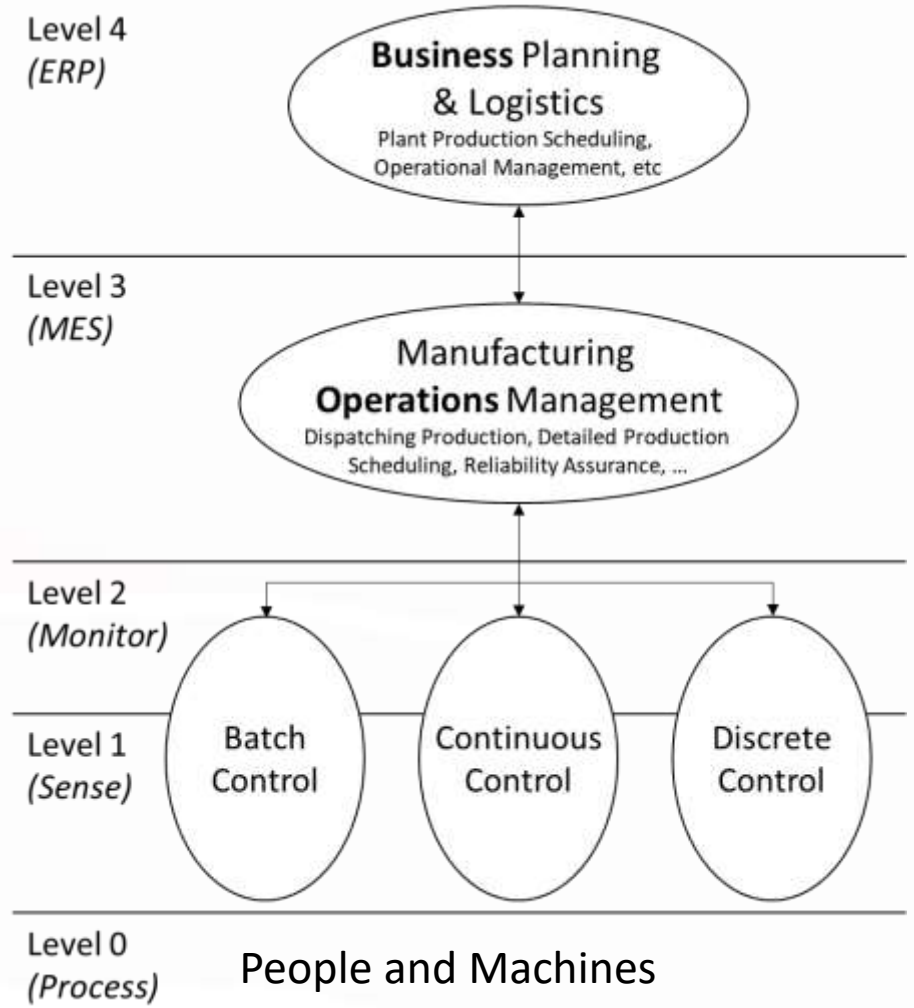
"All I want is a secure system where it's easy to do anything I want. Is that so much to ask?"

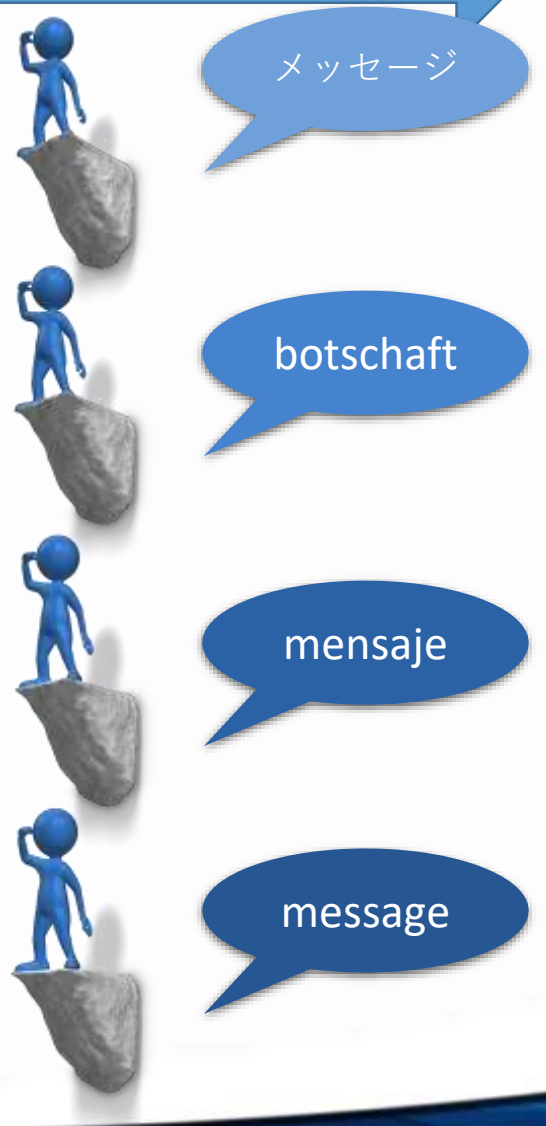


https://xkcd.com/2044/

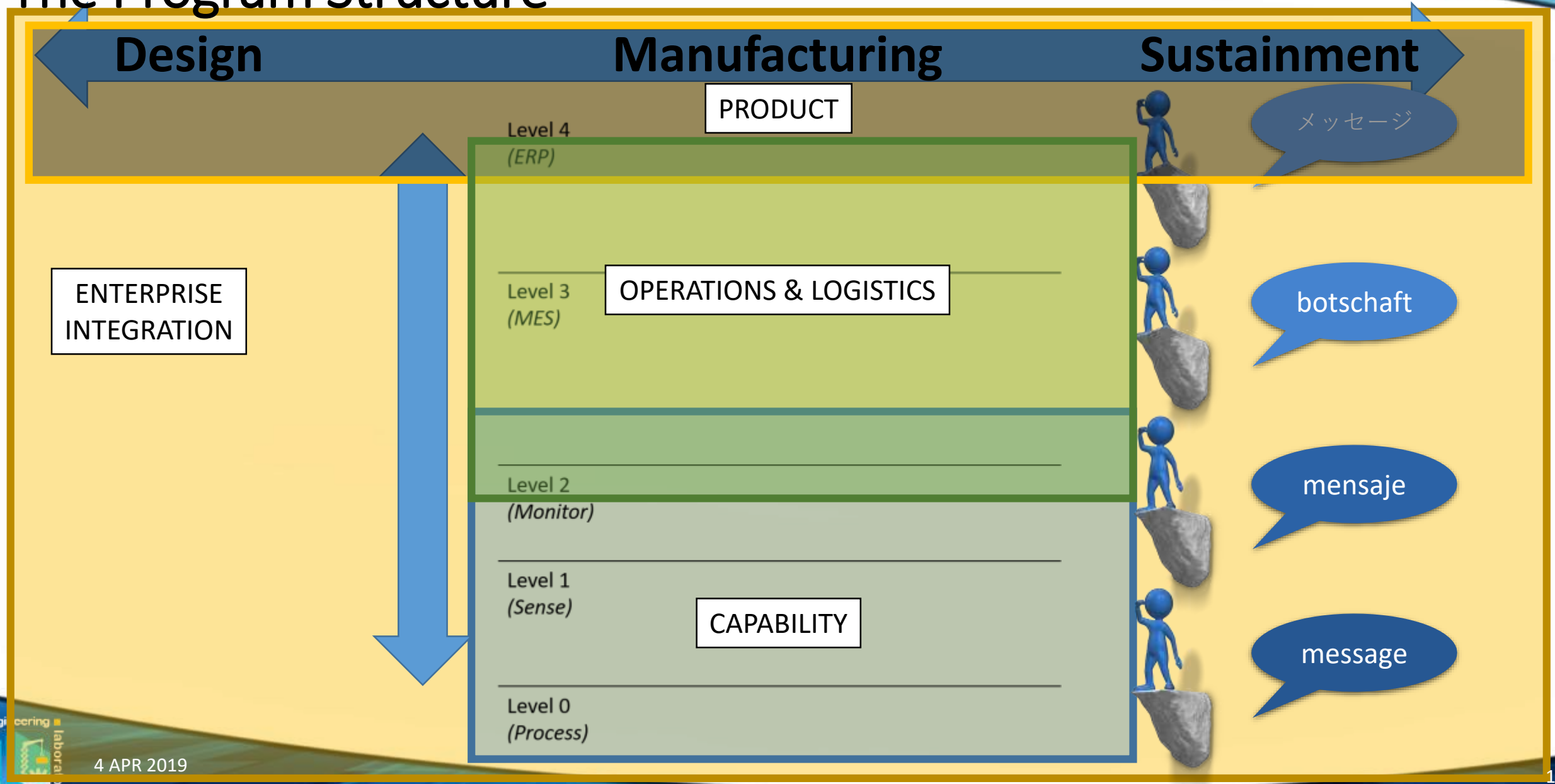
The Problem: Trusted Decision Making in Distributed Environments

Design → **Manufacturing** → **Sustainment**

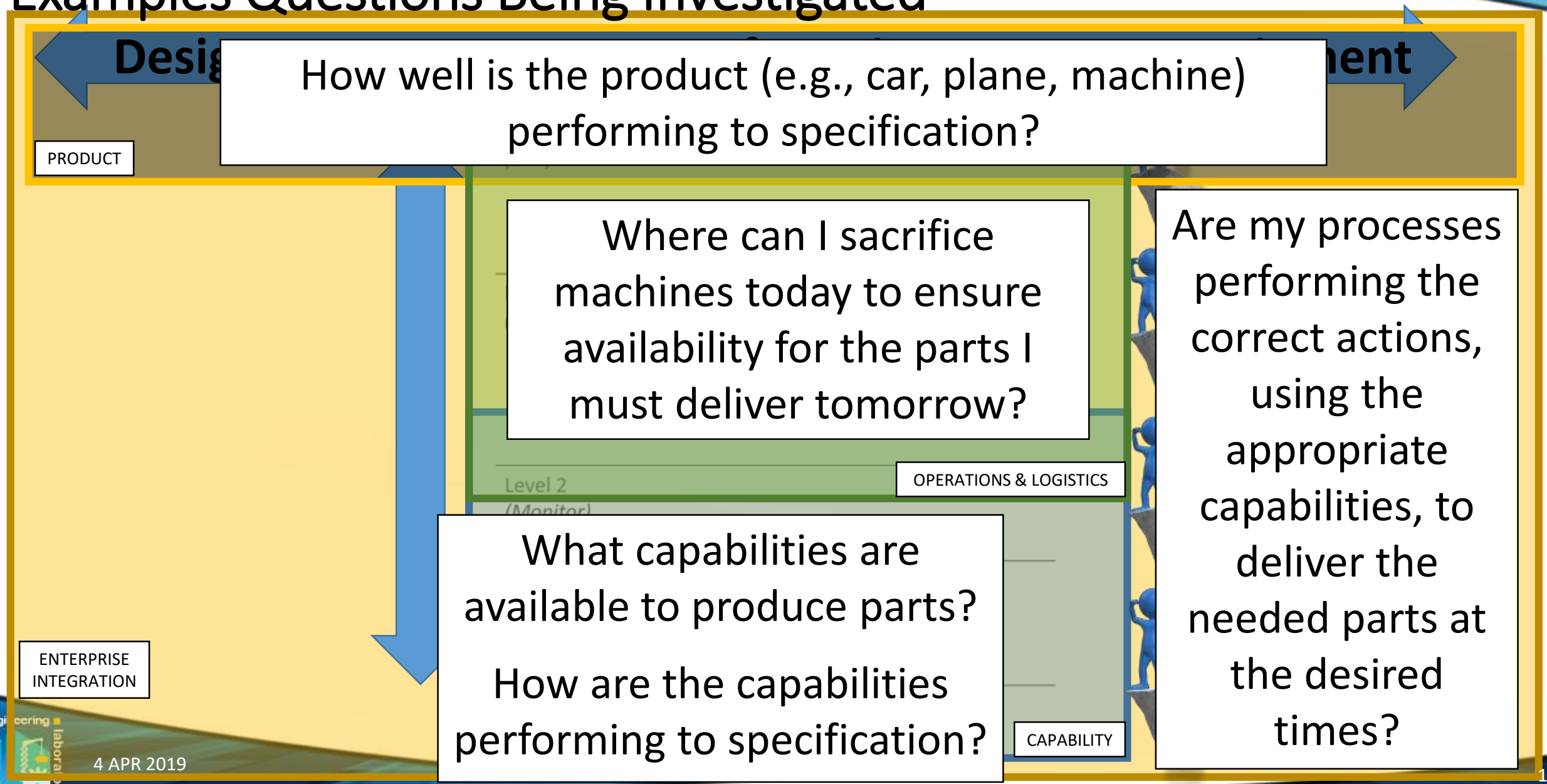




The Program Structure



Examples Questions Being Investigated



MBE Program

Ent. Int.

- Model-Based Systems Definition and Analysis Integration for Smart Manufacturing
- Model-Based Manufacturing Services

Product

- Product Definitions for Smart Manufacturing
- Product Lifecycle Data Exploration and Visualization

Capability

- Model-Based Manufacturing Capability Definition

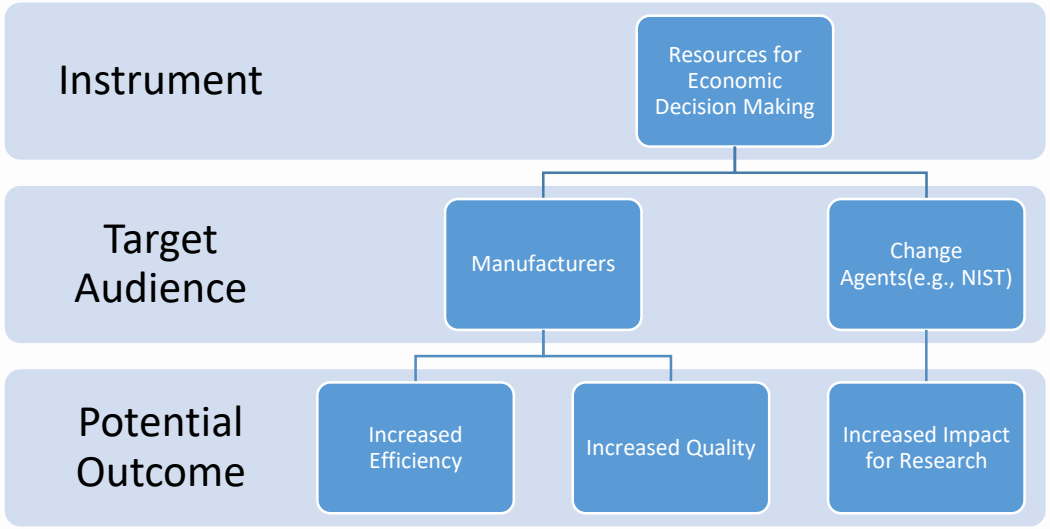
Ops. & Logistics

- Model-Based Smart Manufacturing Operations Management
- Knowledge Extraction and Application for Manufacturing Operations

But wait! There's more…

POC: Doug Thomas, NIST douglas.thomas@nist.gov 301-975-4918

Cost Modeling and Economic Decision Making



Challenge

- Limited tools/methods/data for economic decision making
- As a result, decisions are frequently made using intuition or other non-scientific criteria
- This results in suboptimal outcomes where efficiency and impact are reduced

Expected Major Products

- Method(s) and standard(s) for economic decision making
- Software tool(s) for cost modeling
- Software tool(s) for economic decision making
- Publications on manufacturing costs

Potential Impacts

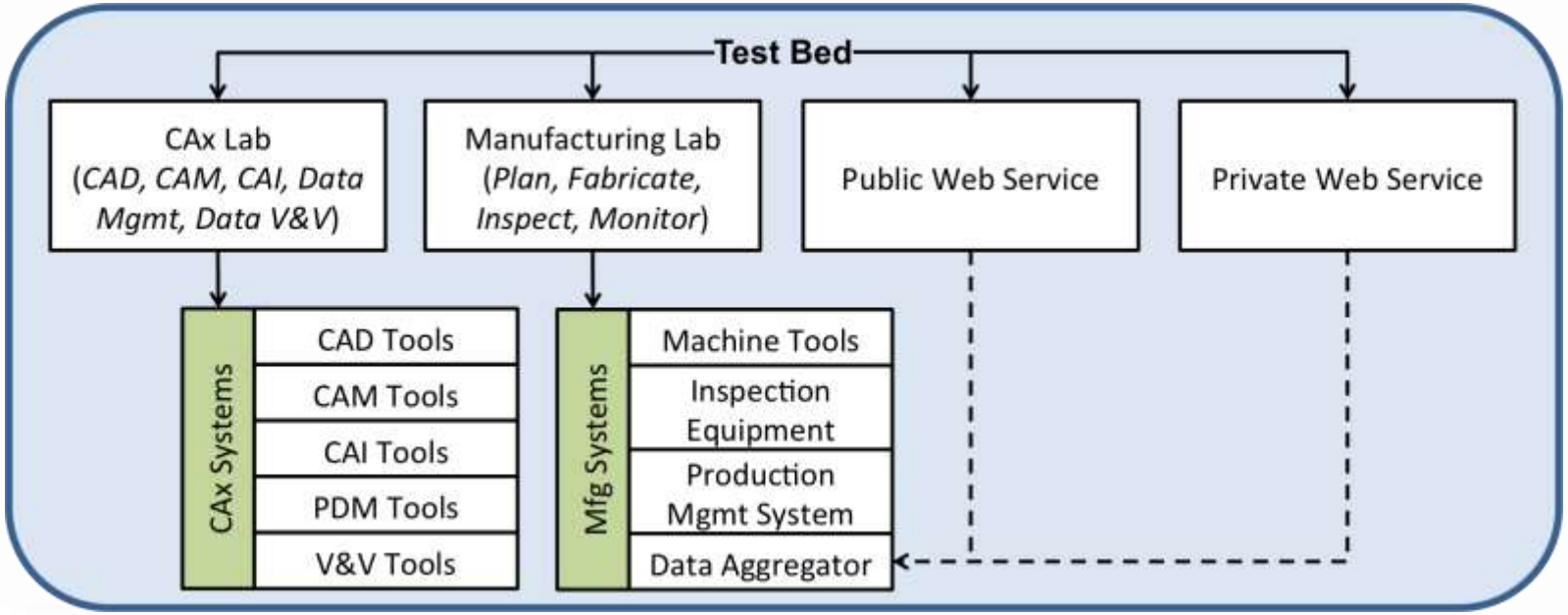
- Facilitate modeling/estimation of manufacturing costs
- Facilitate the identification of high impact research
- Facilitate the identification of high impact manufacturing investments

Objective: To develop and deploy advances in standards, methods, tools, and data for economic decision making

Need Data? NIST Smart Mfg. Systems Test Bed

https://smstestbed.nist.gov

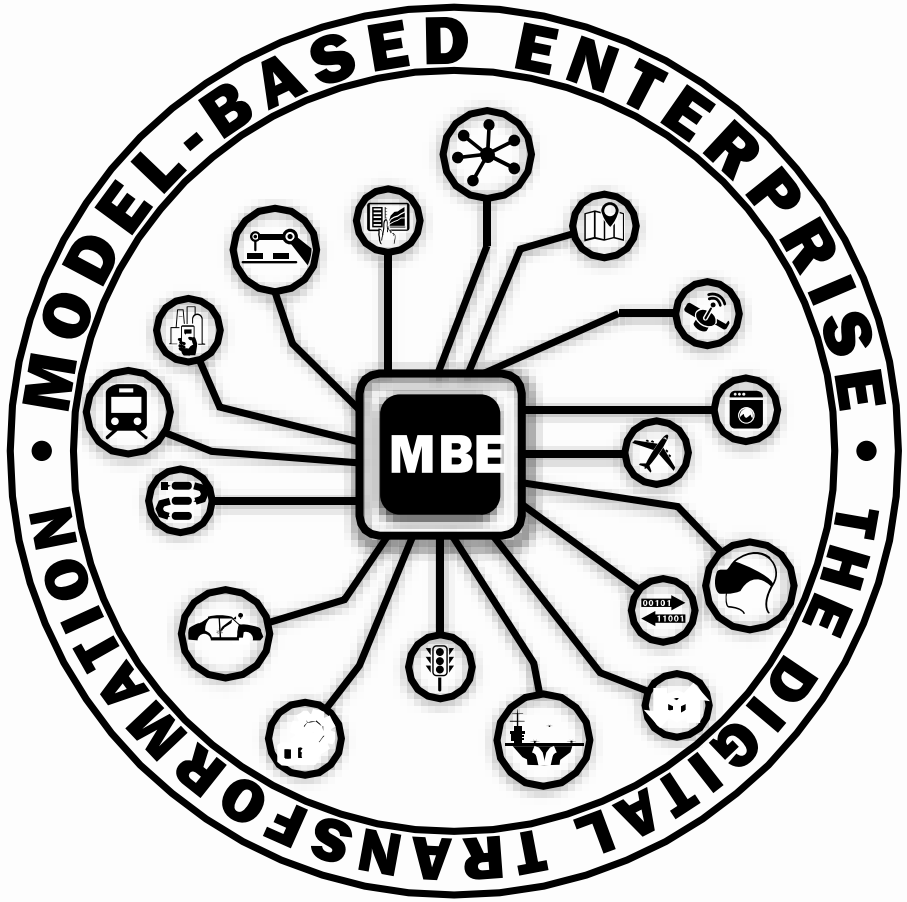
- Reference architecture and implementation
- Rich source of data and test cases for research and education
- Physical infrastructure for standards and technology development



M. Helu, T. Hedberg (2015) Enabling Smart Manufacturing Research and Development using a Product Lifecycle Test Bed. *Procedia Manufacturing*, 1, 86-97. DOI:10.1016/j.promfg.2015.09.066.

Summary

- MBE involves trusted decision making in distributed environments
- Deploying digital thread via standard interfaces between “things” using consensus-based, voluntary, open standards will enable rapid data exploration, knowledge extraction, and model generation
- Conservatively, $100 Billion annual savings* is available to industry through the adoption of open-standards, model-based methods



* Anderson, G. (2016). *The Economic Impact of Technology Infrastructure for Advanced Manufacturing: An Overview* (NIST Economic Analysis Briefs 1). Retrieved from Gaithersburg MD: http://nvlpubs.nist.gov/nistpubs/eab/NIST.EAB.1.pdf

Questions?

Thank you for your kind attention!

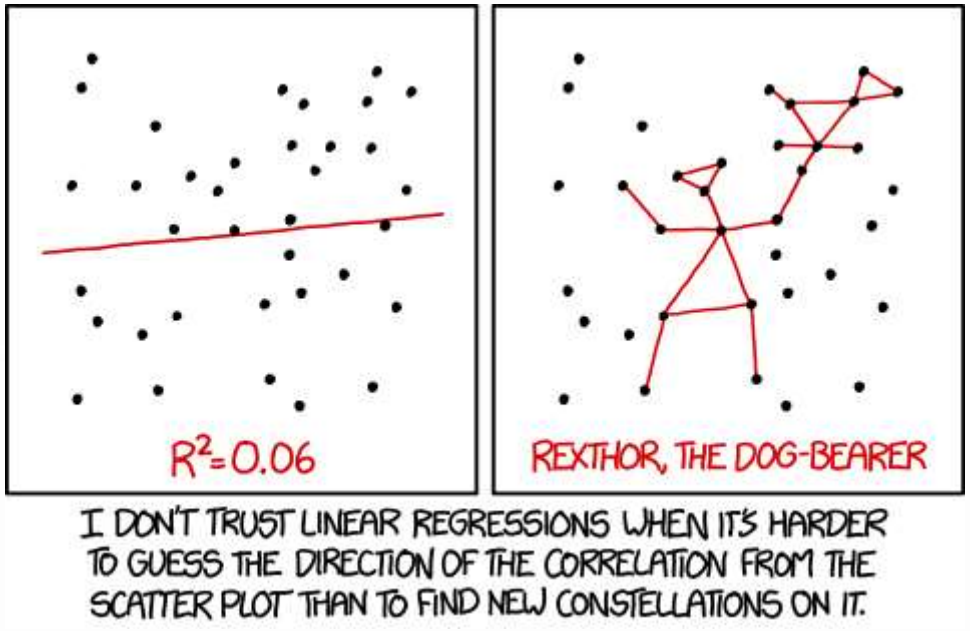
Thomas Hedberg
thomas.hedberg@nist.gov

MBE Program: https://go.usa.gov/xPzGU

SMS Test Bed: https://smstestbed.nist.gov

My Publications: https://go.usa.gov/xnf3w

"The 95% confidence interval suggests Rexthor's dog could also be a cat, or possibly a teapot."



https://xkcd.com/1725/

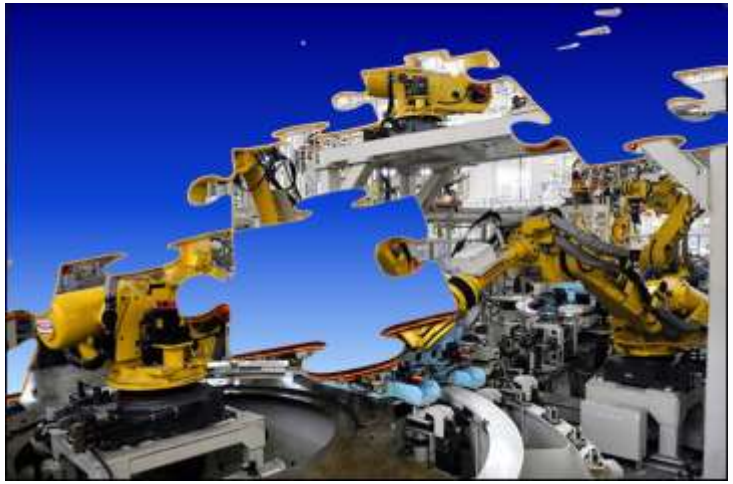
Supplemental graphics used in this presentation were provided by PRESENTERMEDIA and Adobe Stock

Projects Overview

Backup slides

POC: Conrad Bock, NIST conrad.bock@nist.gov 301-975-3818

Model-Based Systems Definition and Analysis Integration for Smart Manufacturing



Challenge

- Smart manufacturing system development and operations are difficult to manage because information about systems and their analysis is expressed in redundant and incompatible ways across the multiple engineering disciplines involved (such as electrical, materials, and process).

Expected Major Products

- Standard tool-independent SysML extensions, models, and transformations for discrete event simulation / optimization, FEA, and logical behavior checking.
- Publicly available software validating the above.

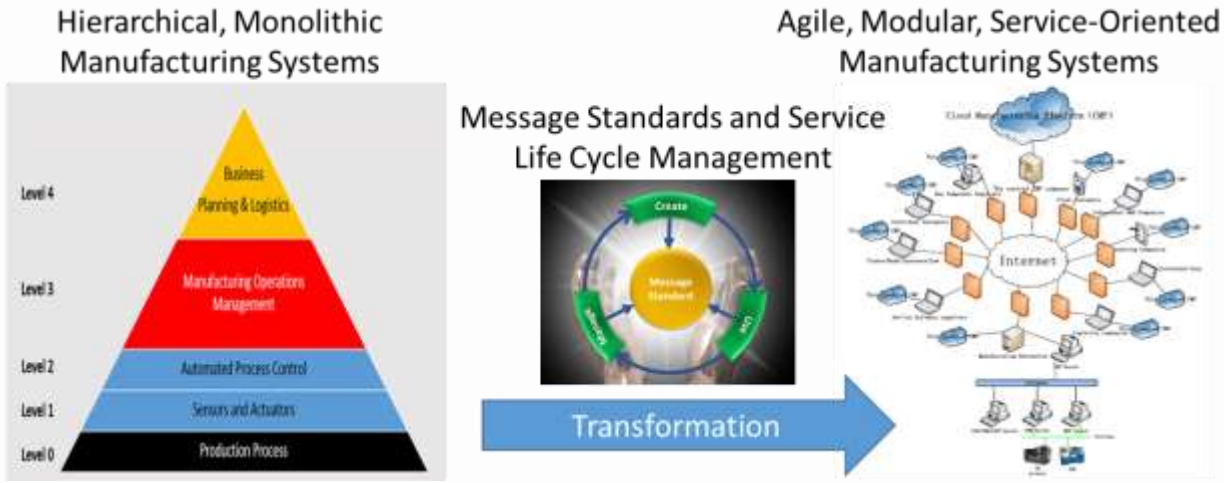
Potential Impacts

- More efficient interaction between systems and analysis engineers leading to shorter time-to-market for complex systems.
- Reduce time and effort to determine whether smart manufacturing system designs will meet requirements and find causes of operational errors.

Objective: To develop and standardize methods and protocols that facilitate analysis of products, processes, and logistics, by unifying domain-specific analysis information and integrating it with systems modeling information.

POC: Serm Kulvatunyou, NIST serm@nist.gov 301-975-2720

Model-based Manufacturing Services



Challenge

- Multiple standards for IoT and manufacturing operations
- Multiple message standard syntaxes
- Multiple integration patterns
- Ambiguous service descriptions

Expected Major Products

- New methods and tools to manage message standards and service descriptions across multiple standards, syntaxes, and integration patterns
- New semantic models for characterizing scheduling service capabilities

Potential Impacts

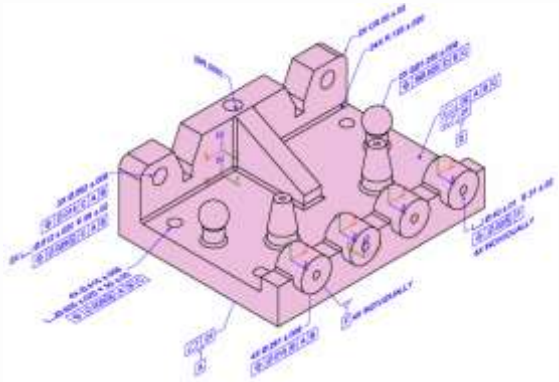
- Reduce risks and costs of transforming manufacturing systems from monolithic, hierarchical architecture to modularized, service-oriented architecture
- Increase in enterprise agility

Objective: To develop and deploy to industry advances in standards and measurement science for model-based messaging standards and service-modeling methodology to enable manufacturers to improve the agility of manufacturing systems.

POC: Robert Lipman, NIST robert.lipman@nist.gov 301-975-3829

Model-Based Product Definitions for Smart Manufacturing

- STEP
- QIF
- MTConnect
- 3D PDF
- ISO
- ASME
- Blockchain



Challenge

- Model-based product definitions standards continue to need: improved methods, protocols and tools for development; conformance testing; increasing user-awareness, and adoption.
- The digital transformation of manufacturing enterprises requires the development of increasingly capable product definition standards for conveying industrial data.

Expected Major Products

- Product definition standards, including PMI, for design, manufacturing, and inspection.
- Improved development processes, testing, and implementations of product definition standards.
- Increased standards awareness by SMEs.

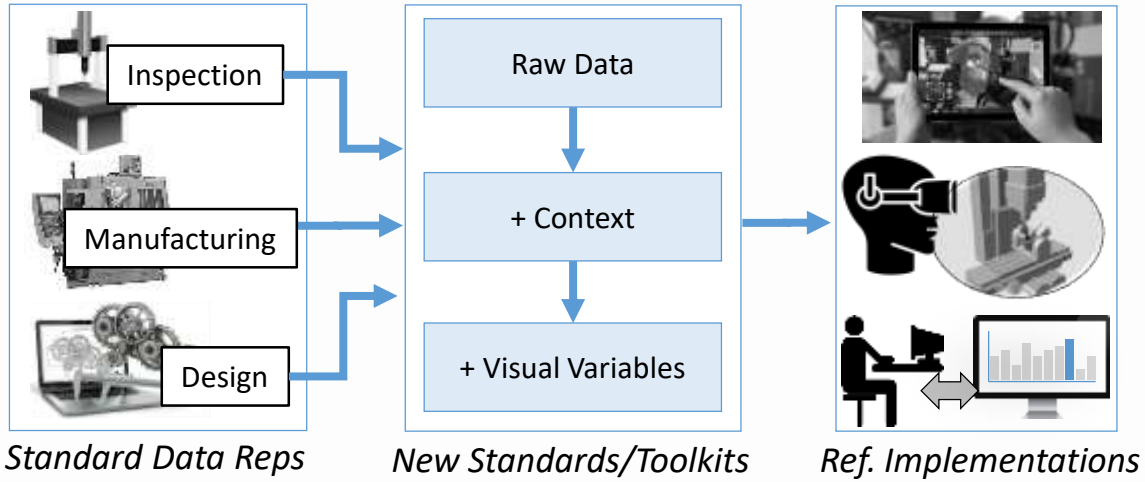
Potential Impacts

- Improved product quality and reduce costs for manufacturers throughout the product lifecycle.
- Reduced costs to develop, test, and deploy product definition standards.

Objective: To develop and deploy advances in standards, conformance testing, user-awareness, and adoption of 3D model-based product definition standards.

POC: Bill Bernstein, NIST wzb@nist.gov 301-975-3528

Product Lifecycle Data Exploration and Visualization



Challenge

- Product lifecycle data is vast, uncertain, complex, multi-modal and sourced from heterogenous data sources.
- Visual analytics (VA) has shown promise for facilitating reasoning in environments with similar characteristics.
- Limited guidance exists for how best to leverage VA in smart manufacturing systems (SMS).

Expected Major Products

- Strategic plan for standards activity for data visualization in SMS
- Reference implementations and toolkits to ease development of data visualization for SMS
- Mapping across standard product representations for system tradespace exploration

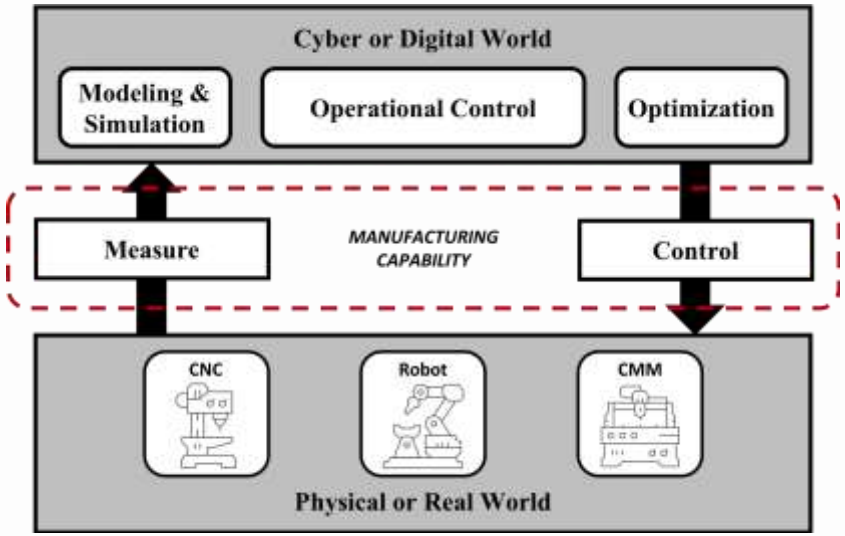
Potential Impacts

- Promote new means of monitoring and reporting SMS activities
- Maturation of evolving standards (e.g., MTConnect)
- Convene and lead a community for standards engagement for visualization for SMS, including data visualization, AR, and VR

Objective: To develop and deploy advances in methods, standards, and software tools for data visualization and exploration for improving the efficiency and agility of smart manufacturing systems.

POC: Moneer Helu, NIST moneer.helu@nist.gov 301-975-3654

Model-Based Mfg Capability Definition



Challenge

- Capability is dynamic
- Abstraction depends on viewpoint
- Large variety of manufacturing systems

Expected Major Products

- Exemplar manufacturing capability models
- Enhancements to MTConnect, ISO 23247, ASME MBE
- Demonstration of manufacturing capability-based control

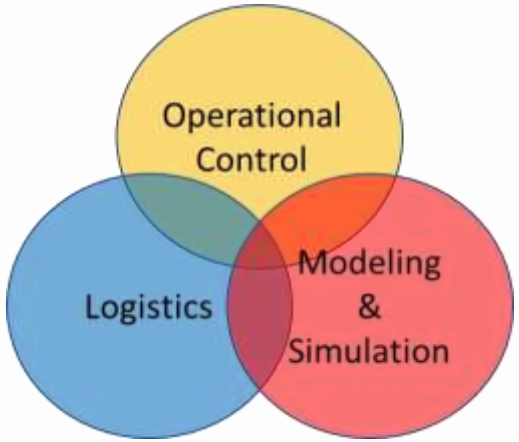
Potential Impacts

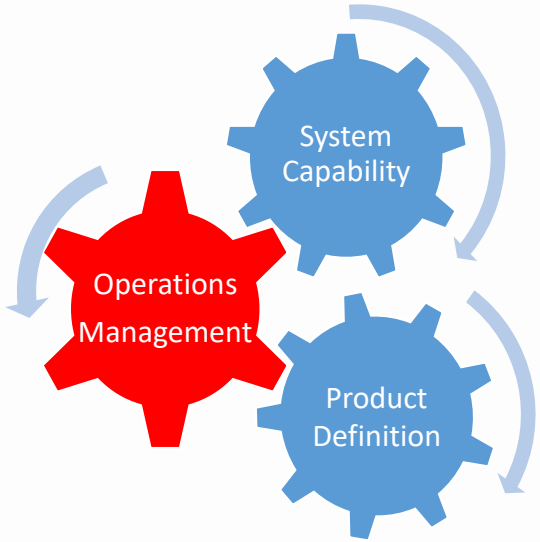
- Improved agility and flexibility in manufacturing by enabling operational control based on measured capability of manufacturing system

Objective: To develop and deploy advances in standards and measurement science to enable manufacturers to define, measure, and control the capability of smart manufacturing systems

POC: Timothy Sprock, NIST timothy.sprock@nist.gov 301-975-0671

Model-based Smart Manufacturing Operations Management





Challenge

- Smart operations management is limited by availability of contextualized integrated information, access to high-quality decision-support tools, and traditional hierarchical operations structures.

Expected Major Products

- Demonstration of model-based operational control capabilities on exemplar models.
- Reference implementations of data management for reliable operations.
- Contributions to **MTConnect**, **PHM**, and **OMG** standards communities.

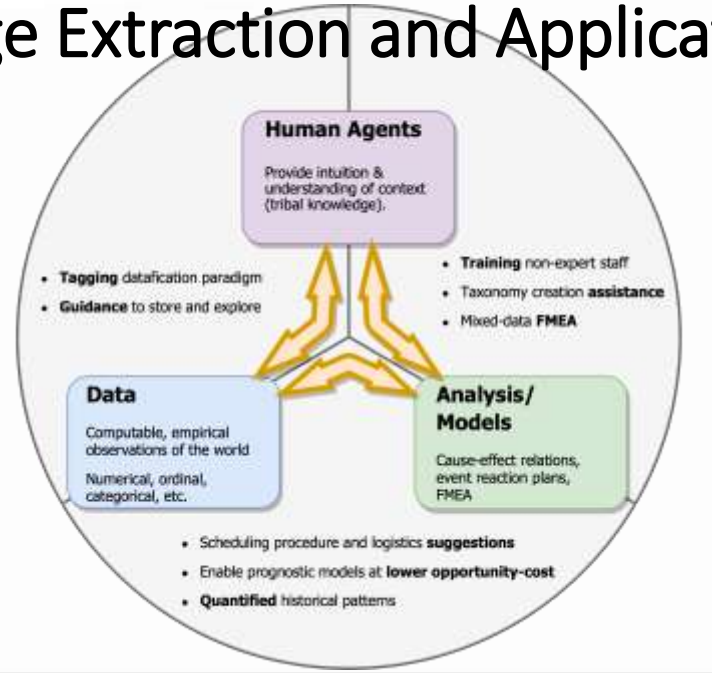
Potential Impacts

- Enable distributed manufacturing through improved operations management capabilities.
- Increased manufacturing system efficiency through improved decision-support capabilities leveraging linked data

Objective: To develop and deploy advances in standards and test methods for operations and logistics that improve the reliability, quality, and efficiency of smart manufacturing systems.

POC: Michael Brundage, NIST mpb1@nist.gov 301-975-8798

Knowledge Extraction and Application for Manufacturing Operations



Challenge

- Human generated text-based documents contain a wealth of manufacturing knowledge, but are underused in analysis due to unstructured nature

Expected Major Products

- Methods for analyzing manufacturing text-based documents
  - Guidelines
  - Toolkits

Potential Impacts

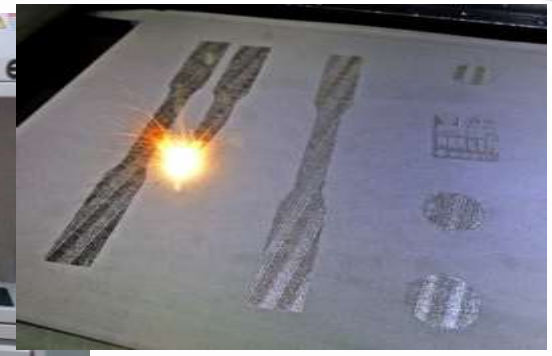
- Provide manufacturers with methods, guidelines, and toolkits for using text-based documents in support of operational decisions on the shop floor

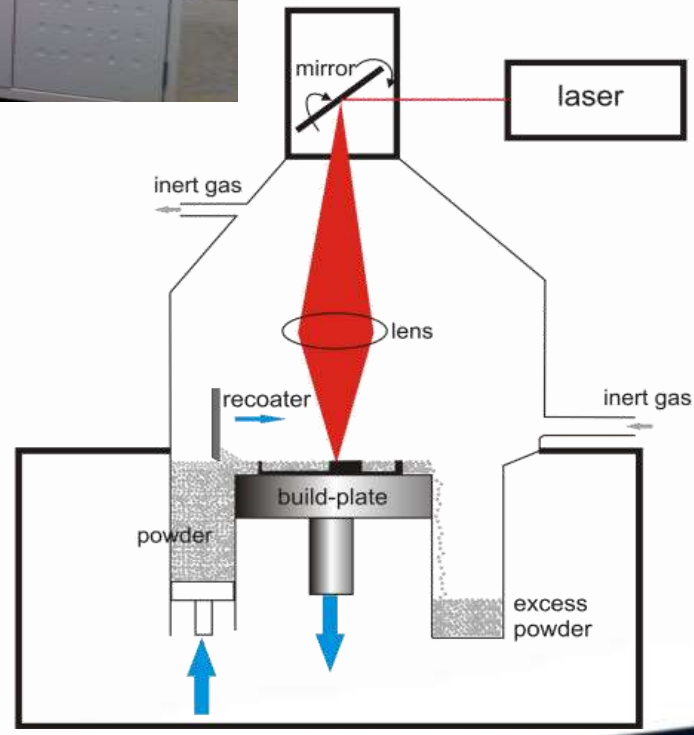
Objective: To develop and deploy advances in standards, measurement science, and software tools using actionable, computable, domain knowledge stemming from informal text-based data to augment a manufacturers' ability to perform model-based and data-driven analyses.

Program Thrusts

AM Thrusts

- Characterization of AM Materials
- Qualification of AM Materials, Processes, and Parts
- Real-Time Monitoring and Control of AM Processes
- Systems Integration for AM





Powder Bed Fusion Process

Robotics Thrusts

- Characterizing Performance of Sensing, Grasping, and Mobility
- Collaborative Robot Systems
- Agility (ease of tasking and re-tasking)
- Interoperability & Integration
- Robots for small and medium-sized manufacturers (SMEs)

Trustworthy Systems, Components, and Data for Smart Manufacturing

- Cybersecurity
- Wireless Communication
- Monitoring, Diagnostics, and Prognostics
- Supply-chain Traceability