Using Standards to Enable Smart Manufacturing on the Shop Floor

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Disclaimer

- Identification of commercial systems does not imply recommendation or endorsement by NIST
- Identified commercial systems are not necessarily the best available for the purpose

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Biography

Moneer Helu is the Acting Division Chief of the Systems Integration Division of the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). His current research focuses on improving agility and flexibility in manufacturing by enabling operational control based on the measured capability of a manufacturing system. He has also made contributions in the areas of green manufacturing, process monitoring, prognostics and diagnostics, and manufacturing data interoperability and management. Helu is a member of the Executive Committee, Standards Committee, and Technical Review Board for MTConnect, Executive Committee of the ASME Manufacturing Engineering Division, and a Corporate Member of the International Academy for Production Engineering (CIRP).

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Outline

- Introduction
- Data collection and synthesis for manufacturing capability
- Scalable data pipeline architectures
- Standardized interfaces for systems integration and control
- Summary

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National Institute of Standards and Technology

- Non-regulatory agency of the Dept. of Commerce
- 3400 employees + 3500 associates
- Two primary campuses: Gaithersburg, MD + Boulder, CO
- Three core programs:
  - NIST Laboratories (7)
  - Hollins Manufacturing Extension Partnership
  - Baldridge Performance Excellence Program

Promote ***U.S. innovation and industrial competitiveness*** by advancing ***measurement science, standards, and technology*** in ways that enhance economic security and improve quality of life

https://www.nist.gov/about-nist

NIST Engineering Laboratory

- Engineering and manufacturing materials, products, processes, equipment, technical data, and standards
- Manufacturing enterprise integration
- Systems integration and engineering
- Intelligent systems and control
- Robotics and automation
- Cyber-physical systems
- Productivity measurement

Promote ***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

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Measurement Science

- Development of critical enabling tools for U.S. manufacturers and industry
- Research that helps establish the technical basis for standards, codes, guidelines, and practices, e.g.:
  - Protocols
  - Performance metrics
  - Guidelines and recommended practices
  - Reference architectures and models
  - Reference data and algorithms
  - Methods for testing, validation, verification, and uncertainty quantification
  - Modeling and simulation tools

Standards ***level the playing field*** and ***democratize innovation***

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What is “Smart Manufacturing”?

- Emerging digital technologies…
- Trend towards automation and data exchange…
- Convergence of IT and OT…
- Industrial Internet of Things…
- Cyber-physical systems…
- Digital threads, tapestries, and twins…
- Mass customization (or batch size one production)…
- The Fourth Industrial Revolution (or Industry 4.0)…

No shortage of buzz!

Smart Manufacturing: Response to Modern Challenges

- Increasingly distributed and decentralized nature of manufacturing
- Growing complexity of modern (global) manufacturing systems
- Need for improved flexibility and agility
- Shortage of skilled workforce
- Changing business drivers and increased global competitiveness

Integration of production systems across the ***product lifecycle*** for the purposes of ***collaboration and coordination*** such that ***data and information*** is leveraged to reduce cost, improve productivity, ensure first-pass success, and augment existing workforce capabilities

T. Hedberg, M. Helu, T. Sprock (2018) *Proc. ASME MSEC2018*, V003T02A019. DOI:10.1115/MSEC2018-6550.

Industrial Internet of Things (IIoT)

- Describes network of objects in an industrial environment that enables information sharing, interaction, and collaboration

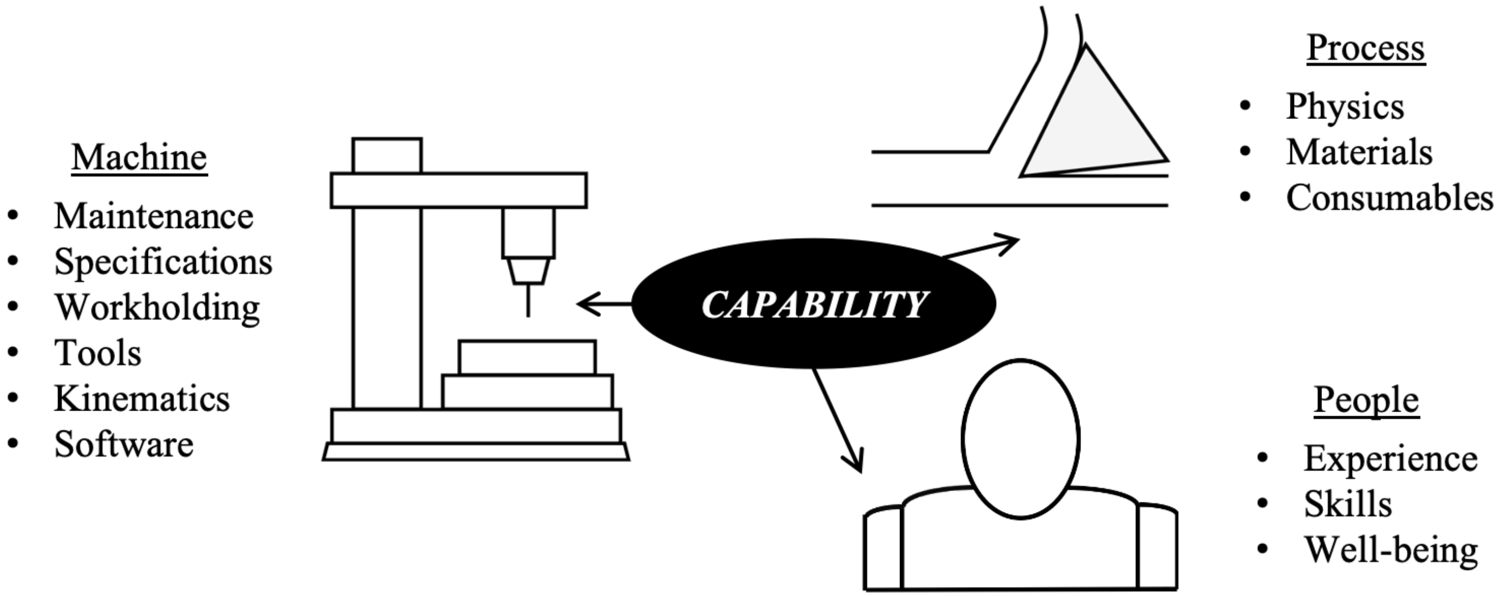
- Enables value generation through transformation of raw data into semantically-rich data that can be curated to created context needed for different viewpoints

- Supports the Model-Based Enterprise, i.e., the use of sharable, interoperable, reusable, machine-readable models throughout the manufacturing enterprise and across the product lifecycle

M. Helu, T. Sprock, D. Hartenstein, R. Venketesh (2020) *CIRP Annals – Manufacturing Technology*, 69(1), pp. 385-388. DOI:10.1016/j.cirp.2020.04.006.

Manufacturing Capability

- Dynamic value provided by a manufacturing asset, resource, or system
- Fundamental part of decision making in production
- Represents one important way to synthesize shop-floor data



Key Considerations:

- Fidelity required by use case
- Large variety of resources
- Dynamic character

M. Helu, W. Sobel, S. Nelaturi, R. Waddell, S. Hibbard (2020) *J. Manufacturing Science and Engineering*, 142(11), 110802. DOI:10.1115/1.4046988.

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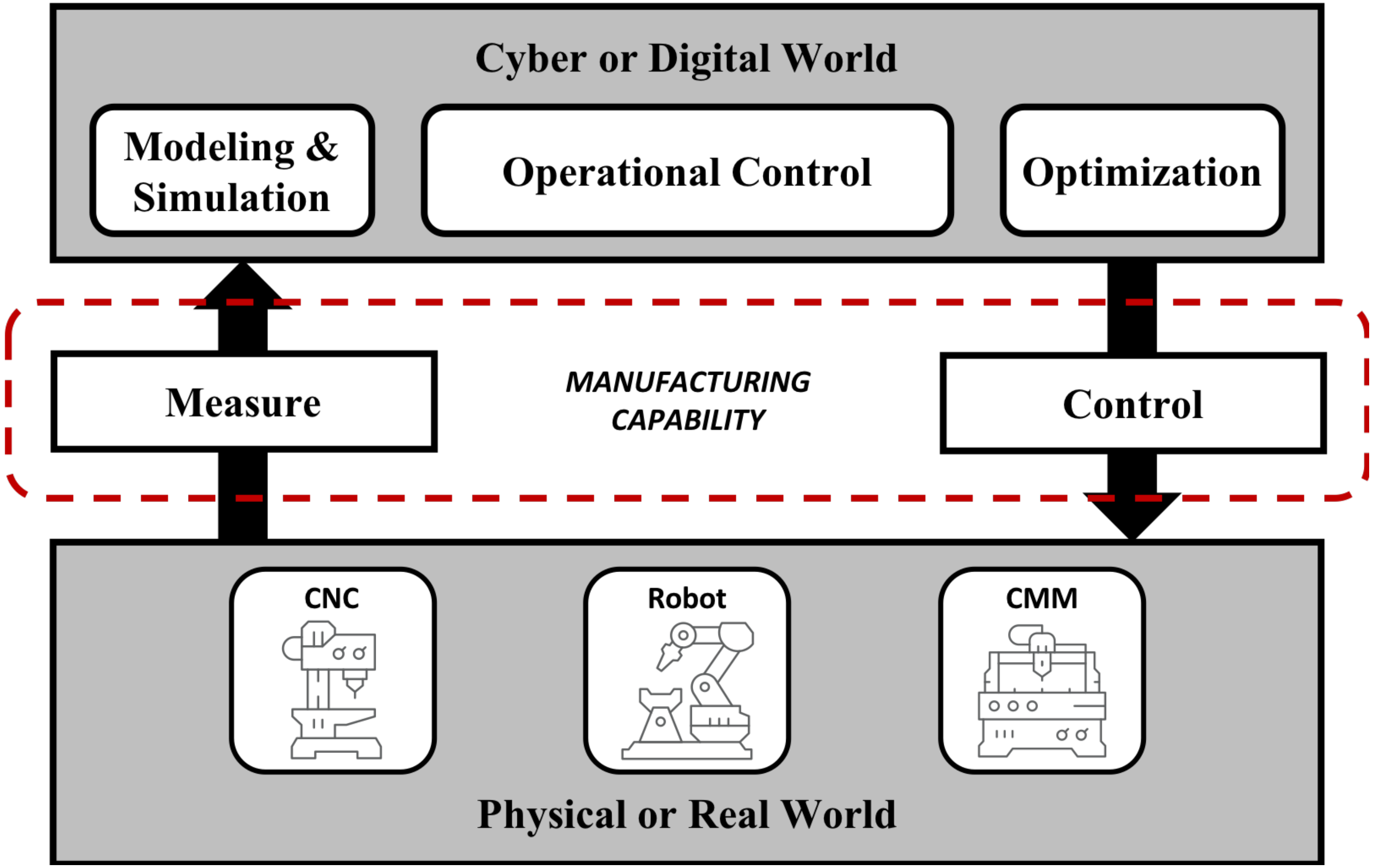
Key Use Cases



- Production Optimization
- On-Demand or Pull Production
- Workforce Management

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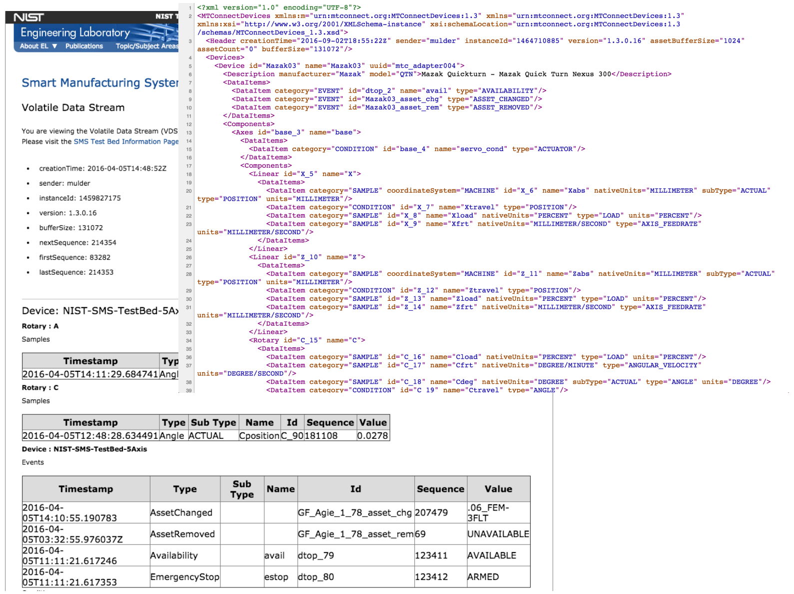
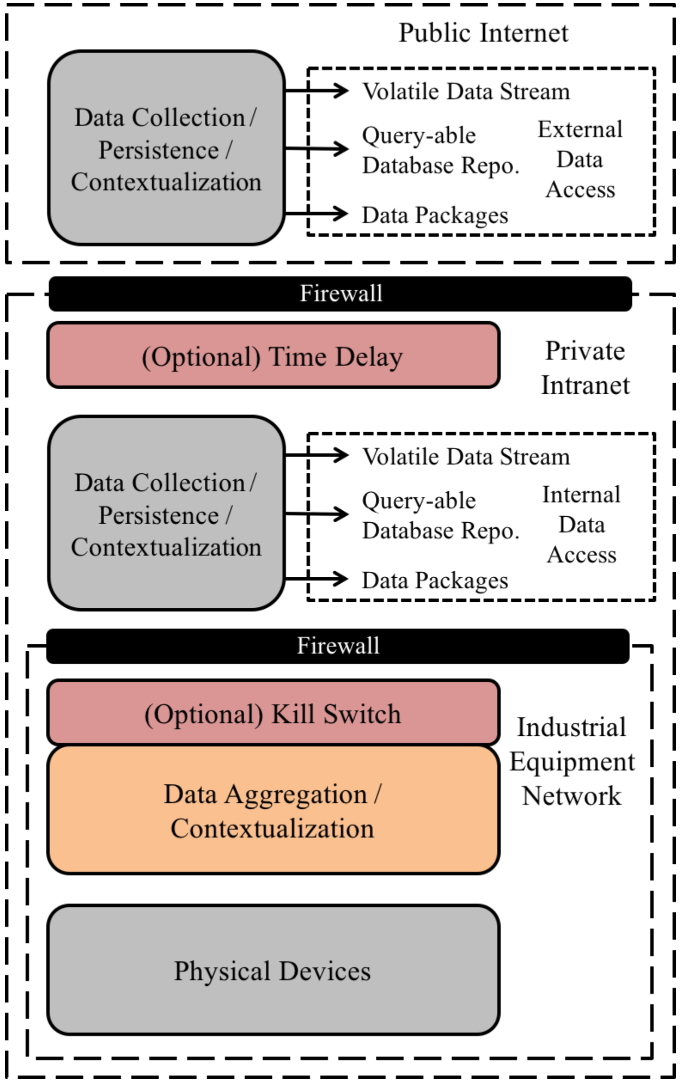
NIST Smart Manufacturing Systems Test Bed

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

Data and documentation available at:
https://smstestbed.nist.gov/





M. Helu, T. Hedberg, A. Barnard Feeney (2017) *J. Manufacturing Science and Technology*, 19, Nov 2017, pp. 191-195. DOI:10.1016/j.cirpj.2017.04.002.

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Unit Manufacturing Process (UMP) Models

Physical World

ASTM E3012

Digital World

Product and Process Information
- Equipment and material specifications
- Process Specifications
  - Setup-operation-teardown instructions
  - Control Programs and process control
- Product and engineering specifications
  - Part geometries
- Production plans
- Quality plans
  - KPIs and quality plans
- PLM and sustainability plans
- Safety documentation

Inputs
- Energy
- Material & consumables
- Outside factors
- Disturbance

Transformation
- Energy
- Material
- Information

Outputs
- Product
- By-Product
- Waste
  - Solid, liquid, emissions
  - Thermal, noise

Resources
- Equipment
- Tooling
- Fixtures
- Human
- Software

Communication

Optimization

Simulation / Design of Experiments

Life Cycle Assessment

Graphical and formal representations

ASTM E3012-20, Standard Guide for Characterizing Environmental Aspects of Manufacturing Processes

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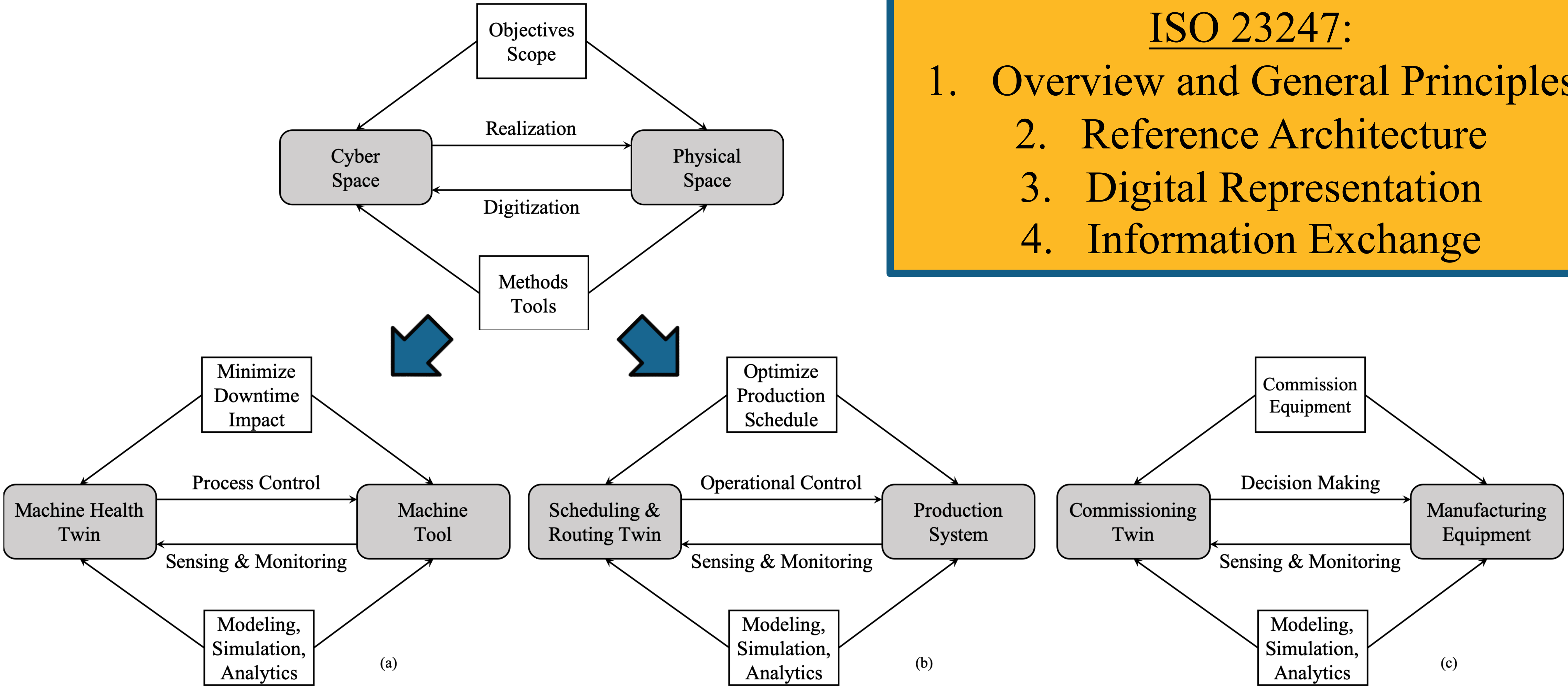
Framework for a Digital Twin in Manufacturing



ISO 23247:

1. Overview and General Principles
2. Reference Architecture
3. Digital Representation
4. Information Exchange

G. Shao, M. Helu (2020) *Manufacturing Letters*, 24, April 2020, pp. 105-107. DOI:10.1016/j.mfglet.2020.04.004.

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Architectual Needs

- Manage data without presupposing use so that data may be used by many applications to maximize value
- Help manufacturers select, configure, and deploy proven data transport and processing solutions developed in non-manufacturing domains
- Enable "plug-and-play" of new data sources and consumers with data processing and distribution at scale while respecting constraints of operational environment with heterogeneous technologies

Develop architecture using enterprise-grade middleware to collect and move data away from shop floor and scale distribution of that data

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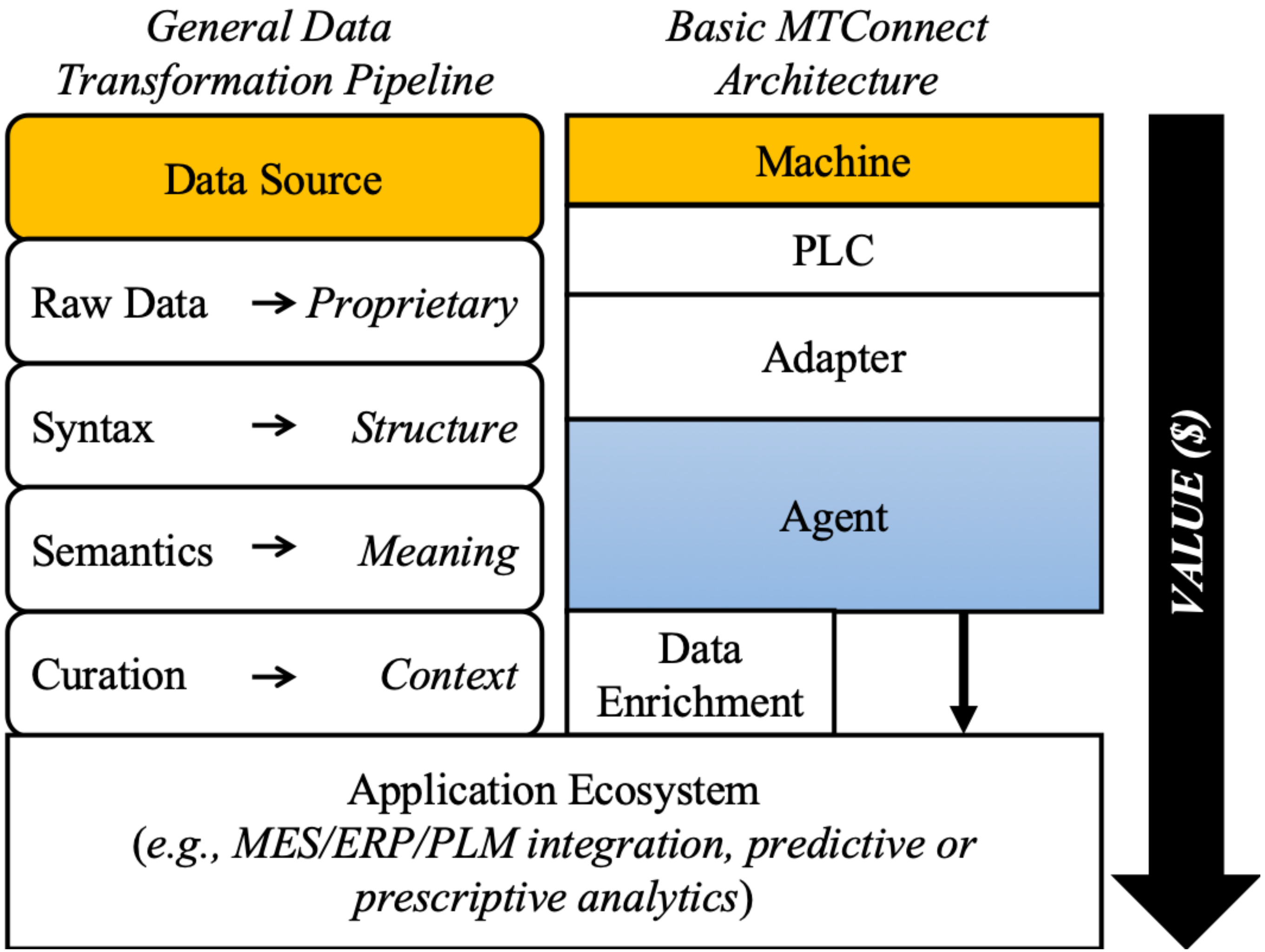
Typical MTConnect Implementation



- Ascribes meaning to shop-floor equipment data using:
  - Controlled vocabulary
  - Typing system
  - Relationships between elements
- Implemented through:
  - Adapter
  - Agent
  - OPC UA companion spec
- Focused on “traditional” database-centric approach

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Analytics Applications in Manufacturing

- Derive insight (or actionable information) from data using systematic analysis
- Focus primarily on database-centric approach that relies on relatively large datasets pre-stored in curated databases
- Differ from other data-rich domains that primarily rely on timely transformation and distribution of streaming data for many applications

Lambda Architectures

- Speed → continuous analysis to provide feedback before value is lost
- Batch → periodic (or on-demand) analysis of historical data for more complex assessment
- Separation of concerns is essential

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Architectural Concerns

- Format data into standardized data types
- Synchronize data stamps to assert causality of events from multiple sources
- Use OEM knowledge to translate PLC tags and units into standardized controlled vocabularies and data formats
- Enable deployment on embedded or legacy systems
- Manage continuity of data stream and recovery
- Ensure data provenance can be asserted by applications
- Ensure security of equipment from external incursions
- Route information flows to multiple endpoints
- Enable data persistence in a permanent immutable store

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Specific Architectural Concerns

- Placement of technology solutions depends of trade off between:
  - Criticality of response time → OT
  - Ease of maintenance → IT
- Middleware focused on IT to better address the following:
  - Merge heterogeneous data streams, including MTConnect-compliant and ad-hoc data sources
  - Ensure scalability and elasticity with respect to memory, processing power, and bandwidth
  - Maintain existing or comparable interfaces at scale
  - Provide high availability of critical components

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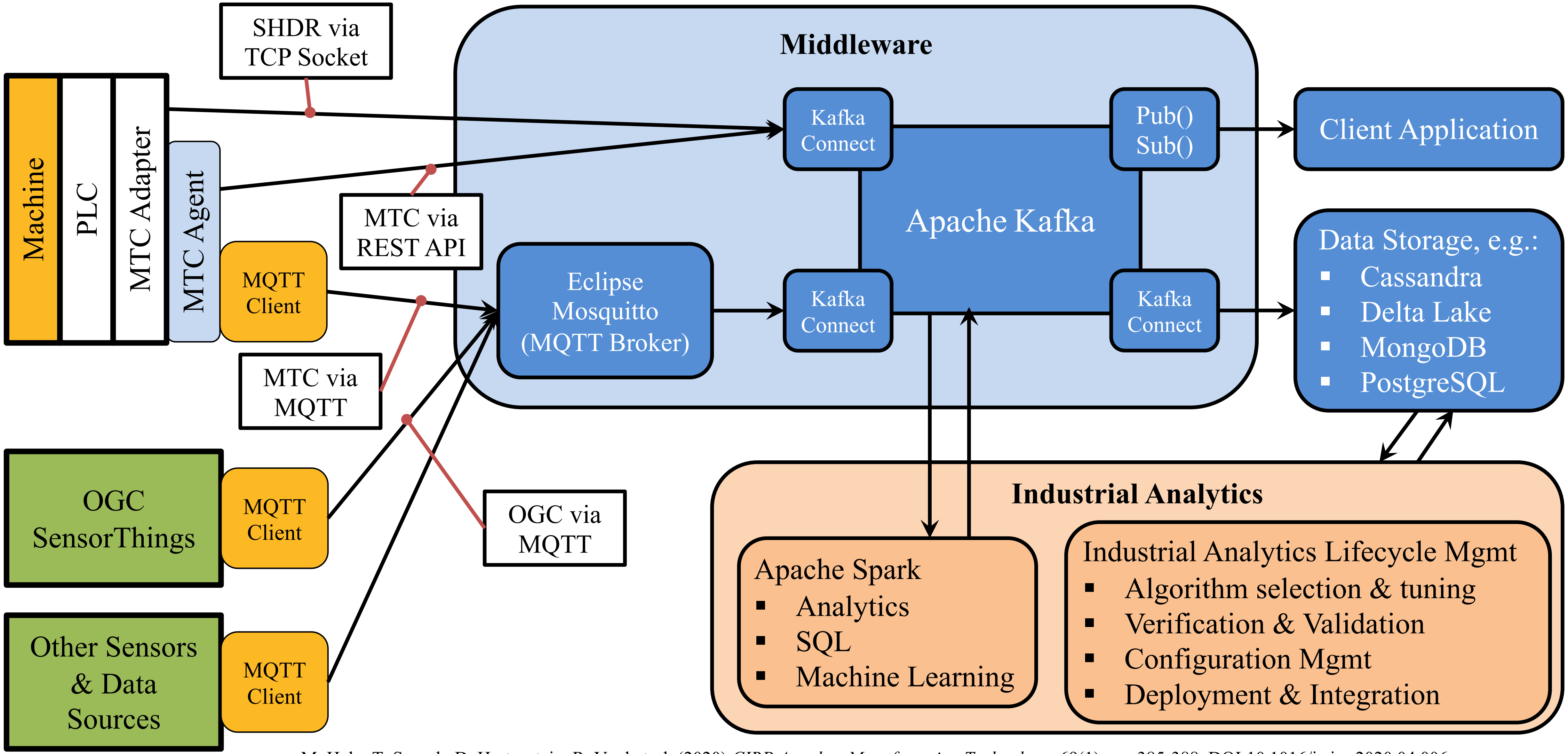
Proposed Shop-Floor IIoT Architecture



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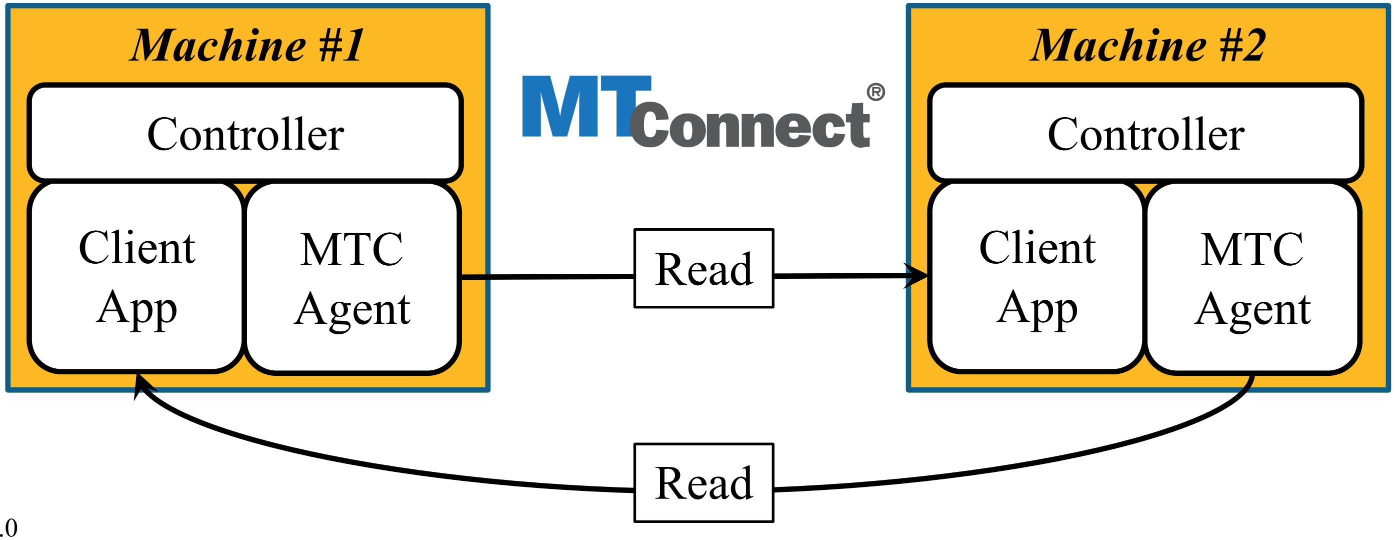
Standard Interfaces for Systems Integration

- Standard language and interaction model for machines to communicate
- New decision-making and control paradigms that balance orchestration and choreography
- Clearly defined "market" to inform decision making and control



MTConnect Standard, Part 5 – Interfaces, Version 1.5.0
M. Helu, W. Sobel, S. Nelaturi, R. Waddell, S. Hibbard (2020) *J. Manufacturing Science and Engineering*, 142(11), 110802. DOI:10.1115/1.4046988.

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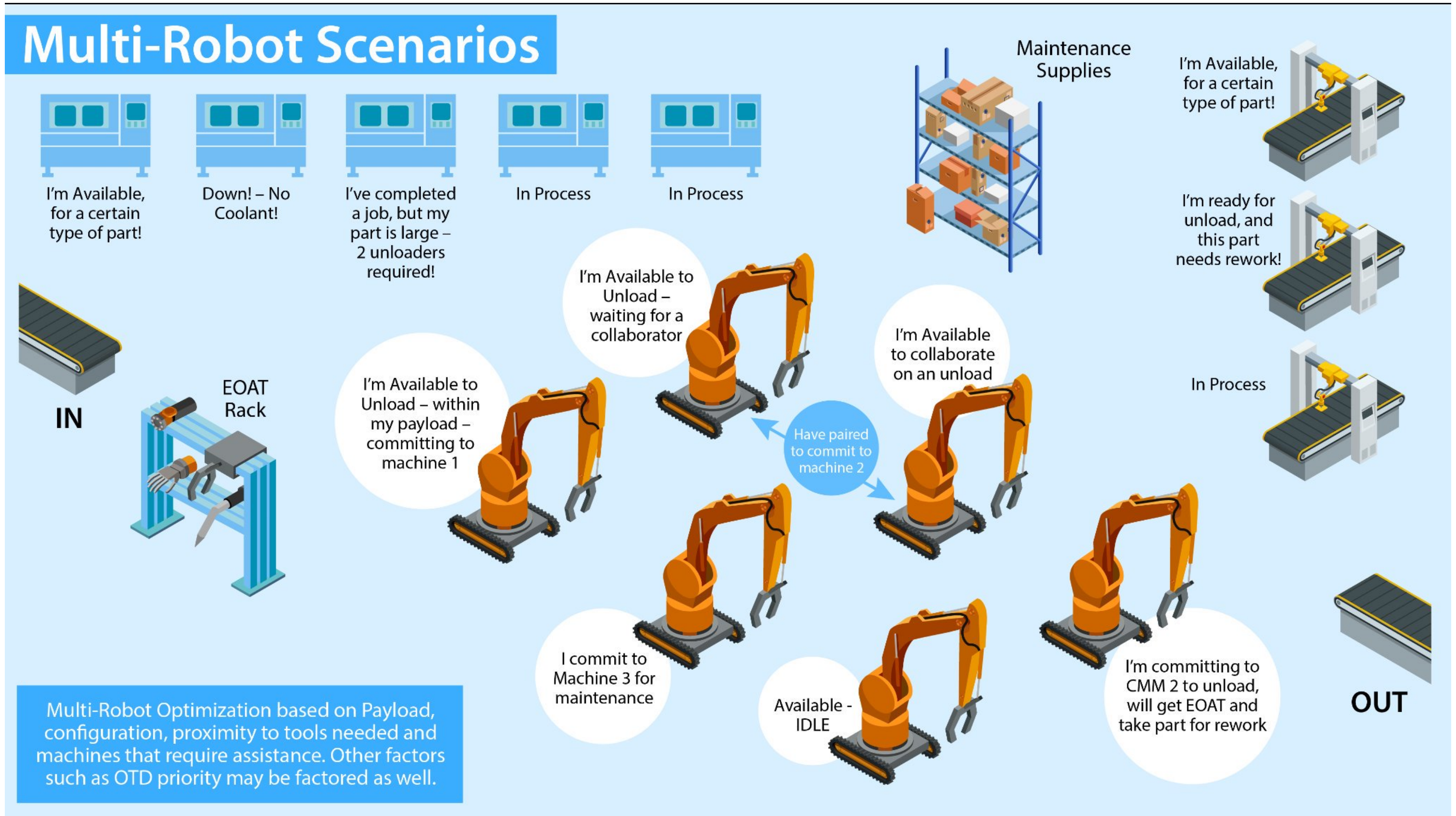
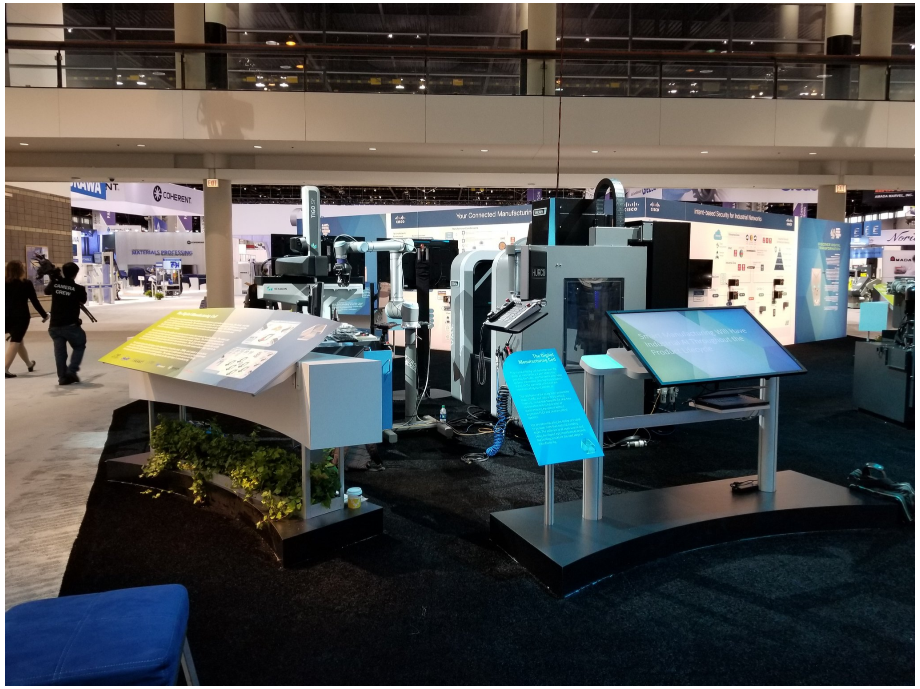
Example: Low-Cost, Scalable Automation





MTConnect® ROS industrial SwRI® AMT THE ASSOCIATION FOR MANUFACTURING TECHNOLOGY IMTS2018

SwRI/VIMANA/AMT, Emerging Technology Center @ IMTS2018
https://rosindustrial.org/news/2018/9/28/imts-2018-leveraging-open-standards-and-technologies-to-re-imagine-interoperability-within-factories

Summary

- Smart manufacturing enables dynamic production systems and rapid design-to-production transformation through the integration of production systems across the product lifecycle
- Model-Based Enterprise and IIoT are two critical pieces of smart manufacturing that allow for the sharing of data, information, and knowledge across networked production systems
- Standards are key to implementing the Model-Based Enterprise and IIoT on the manufacturing shop floor

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Thank you for your kind attention!

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