# Connecting and Deploying Smart Manufacturing Technology to Support PHM

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**NIST Industry Forum**

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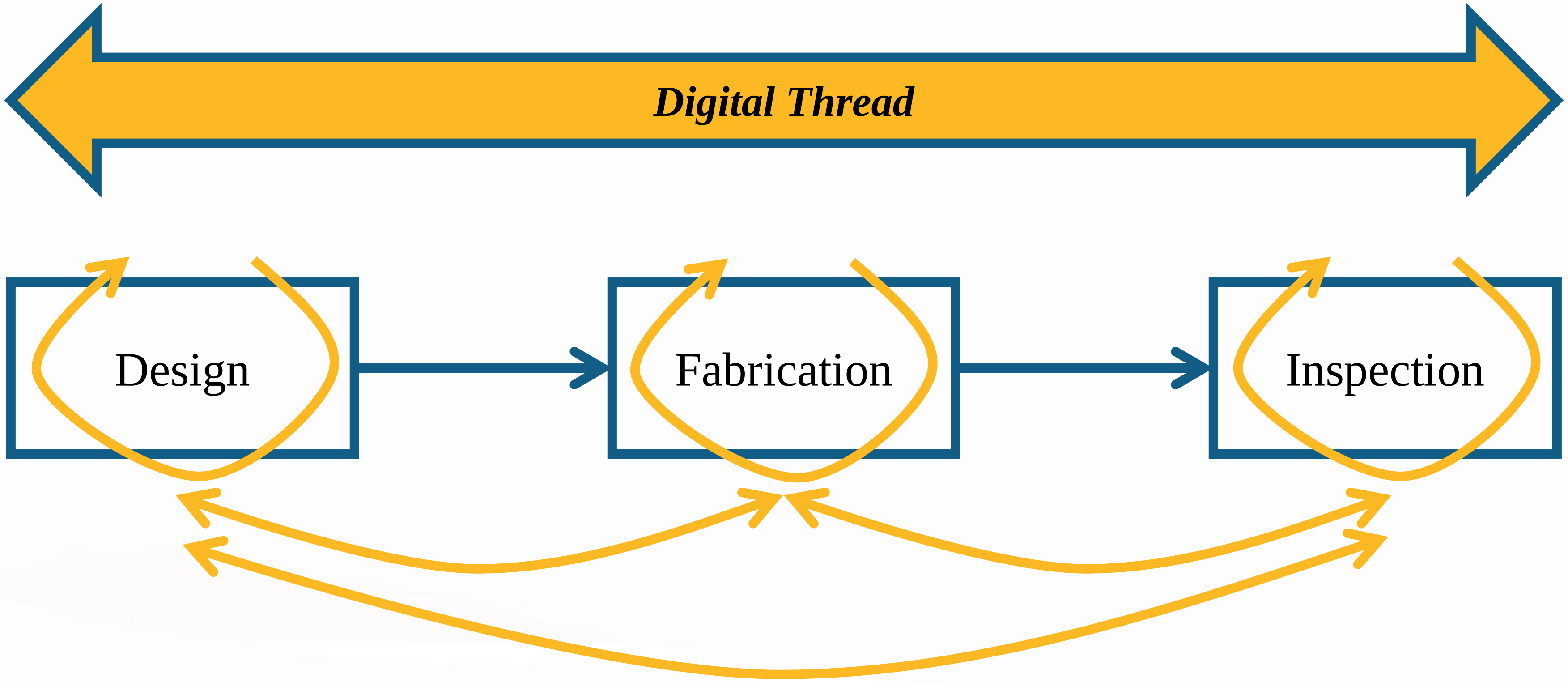
# Disclaimer

- Identification of commercial systems does not imply recommendation or endorsement by NIST

- Identified commercial systems are not necessarily the best available for the purpose

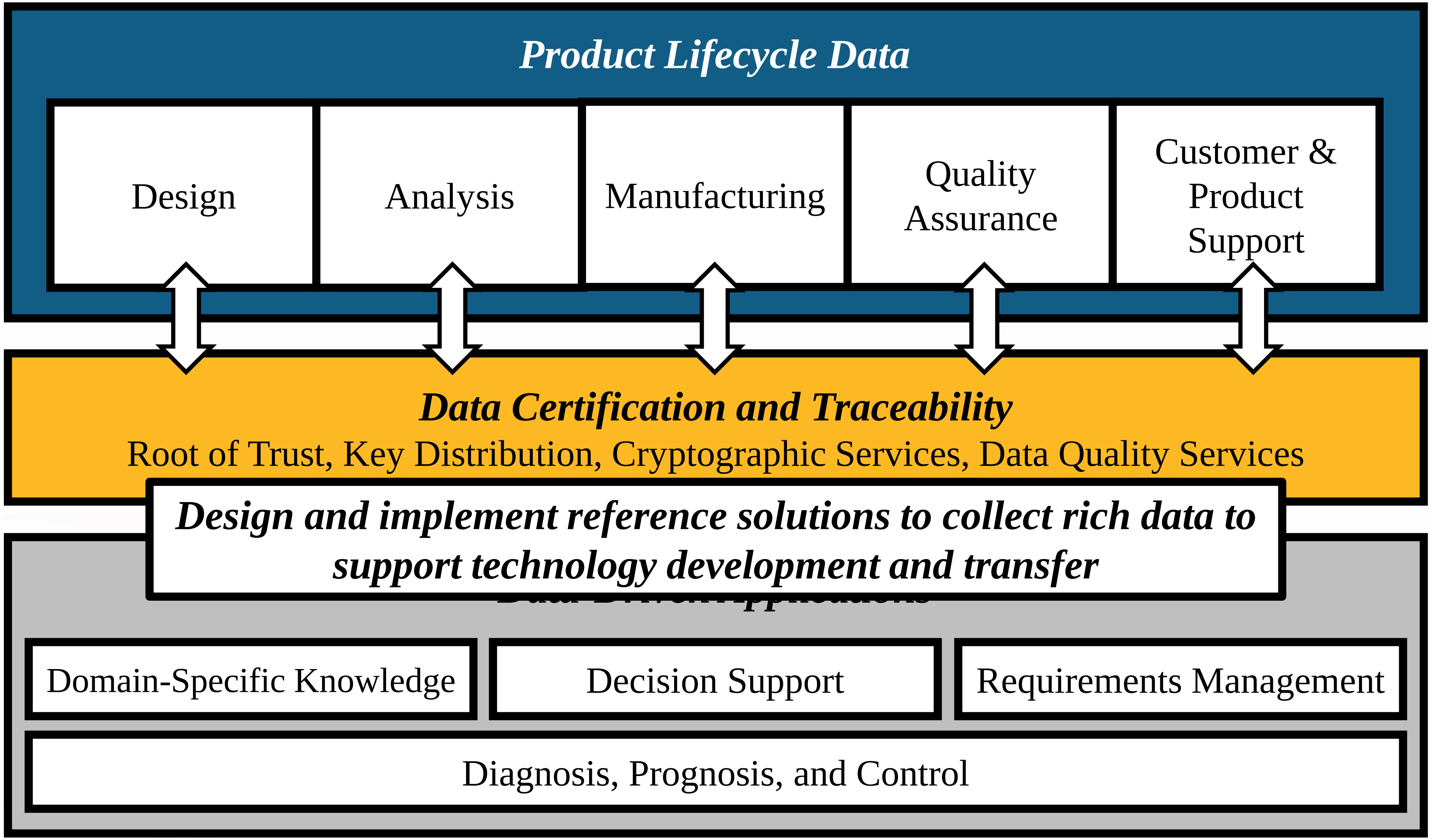
# The Digital Thread Concept




***Information sharing across the digital thread can improve the overall performance of the product design and manufacturing process***

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.

# Lifecycle Information Framework




T. Hedberg, A. Barnard Feeney, M. Helu, J. Camelio (2016) Towards a Lifecycle Information Framework and Technology in Manufacturing. *J. Computing & Info. Sci. in Eng*. DOI:10.1115/1.4034132

# Current Challenge

- PLM solutions:
  - CAx: CAD, CAE, CAM, etc.
  - PDM
  - V&V

Primarily IT;
Engineering focused;
Relatively expensive

- Operations solutions:
  - Devices, SCADA, PLC
  - MES, MOM
  - ERP

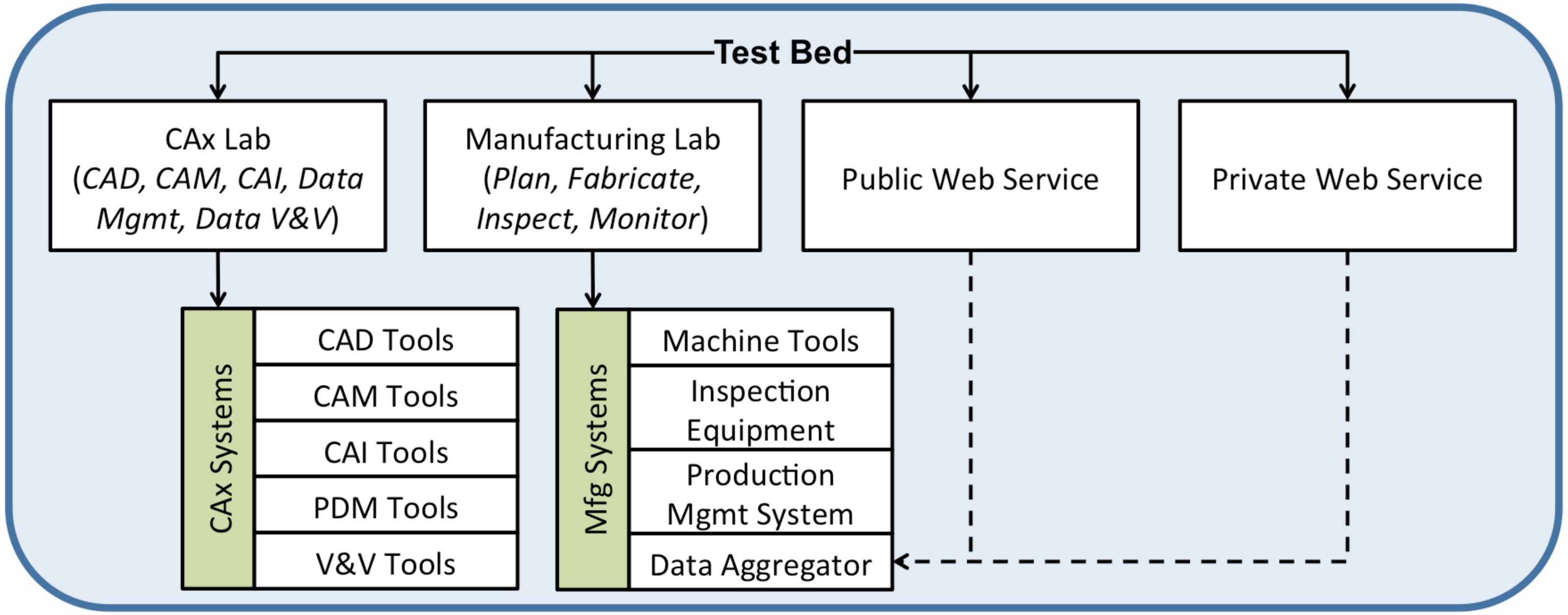
Mixture of IT and OT;
Lack of integration
across control levels

***Integration of heterogeneous solutions across the product lifecycle for SMEs and larger organizations***

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.

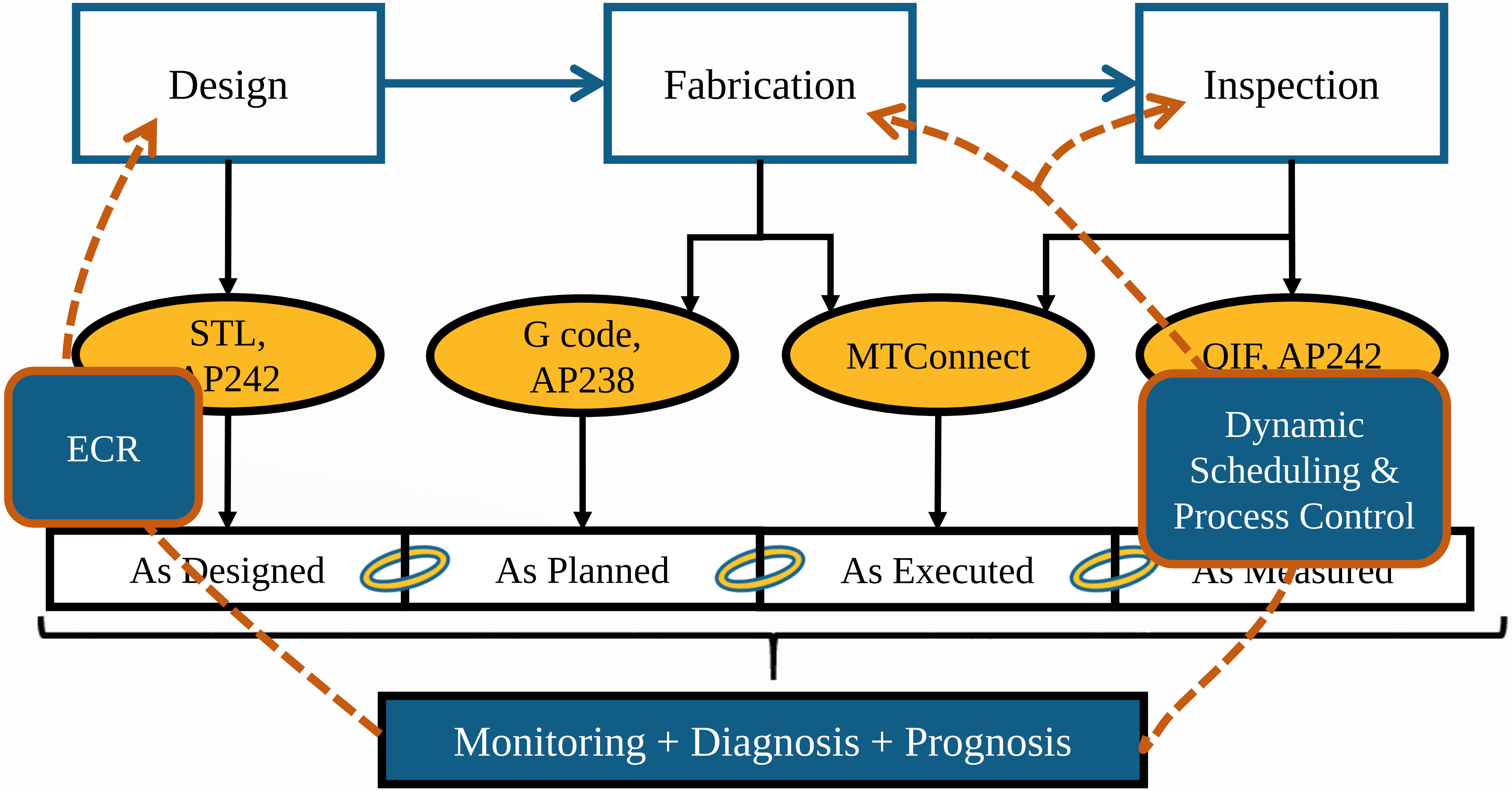
# NIST Smart Mfg. Systems Test Bed

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




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.

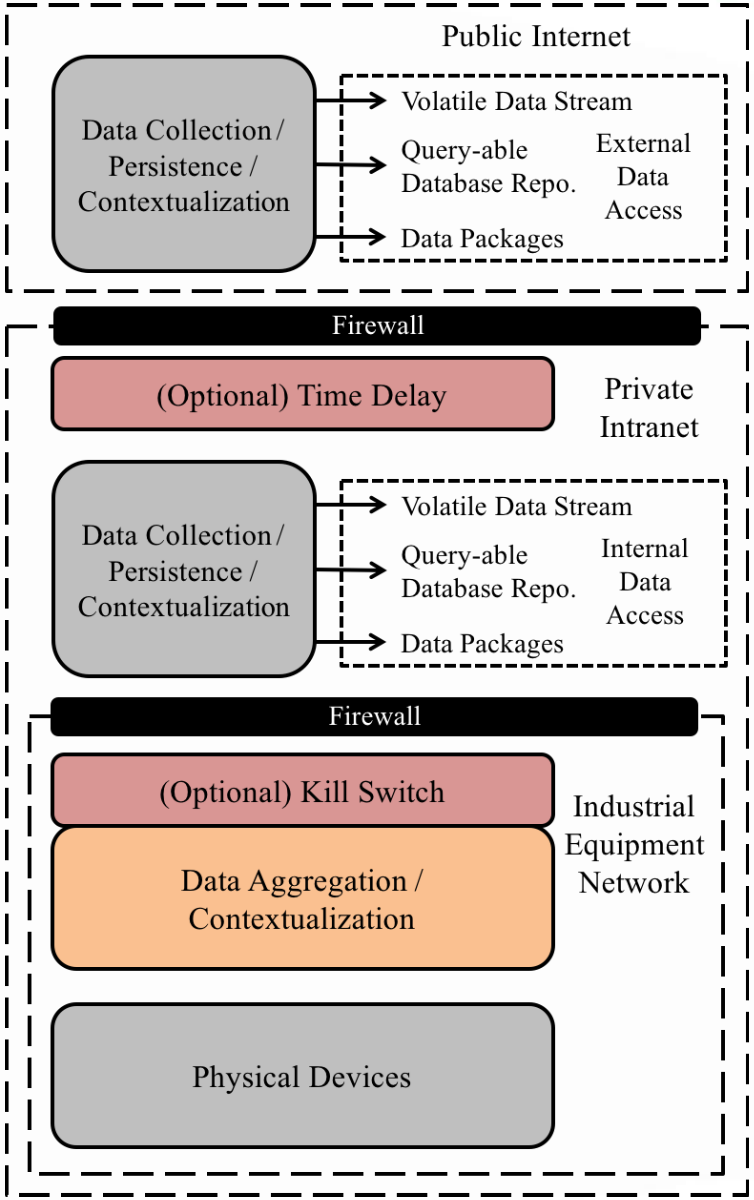
# Data Collection and Aggregation




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.

# Manufacturing Data Architecture

- Designed as a four-tier architecture
- Implemented across three networks
- Provides segregated access to internal and external clients




M. Helu, T. Hedberg, A. Barnard Feeney (2017) Reference Architecture to Integrate Heterogeneous Manufacturing Systems for the Digital Thread. *J. Mfg. Sci. & Tech.*, 19, 191-195. DOI:10.1016/j.cirpj.2017.04.002.



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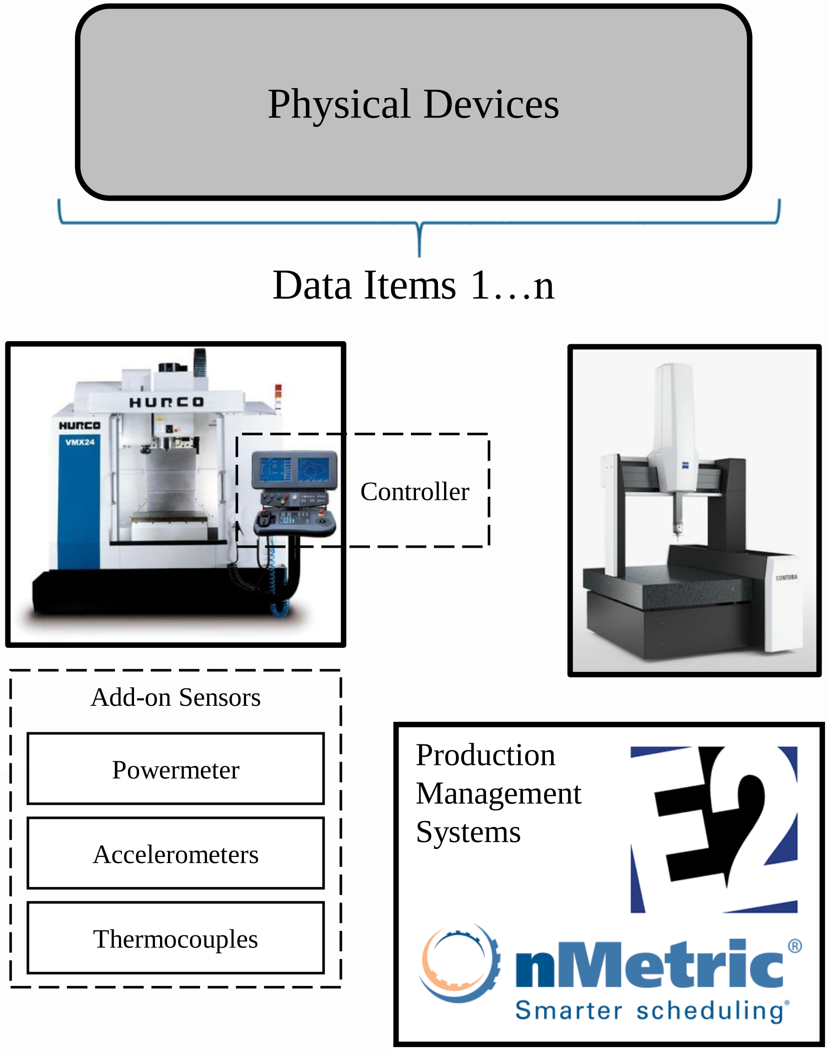
# Tier #1: Services

- Shop-floor IT and OT systems
- External sensors and equipment
- Any additional sources of data

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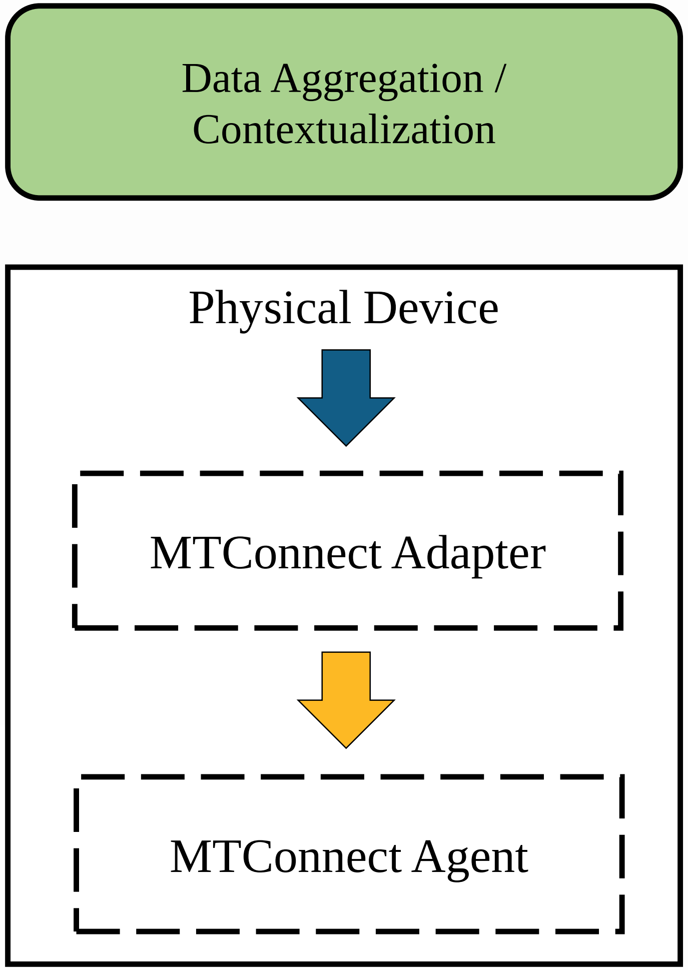
# Tier #2: Aggregation

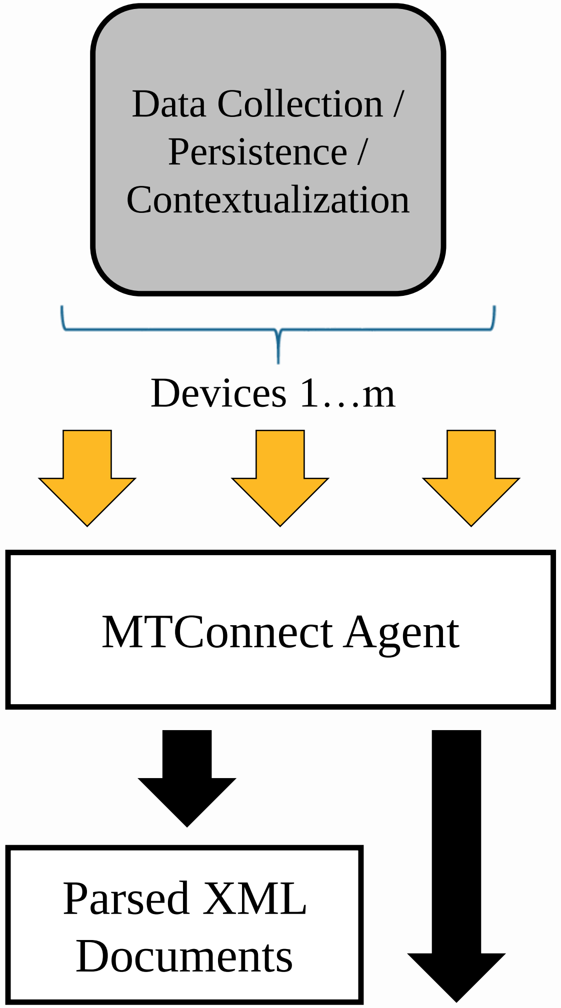
- Aggregates and contextualizes service data
- Provides data protocol translation
- Supplies data and information structure for underlying services




M. Helu, T. Hedberg, A. Barnard Feeney (2017) Reference Architecture to Integrate Heterogeneous Manufacturing Systems for the Digital Thread. *J. Mfg. Sci. & Tech.*, 19, 191-195. DOI:10.1016/j.cirpj.2017.04.002.

# Tier #3: Delivery

- Processes and contextualizes data for delivery to client
- Caches content for efficient performance
- Enables further development through data analytics

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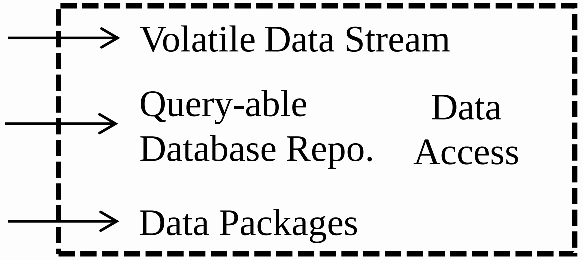
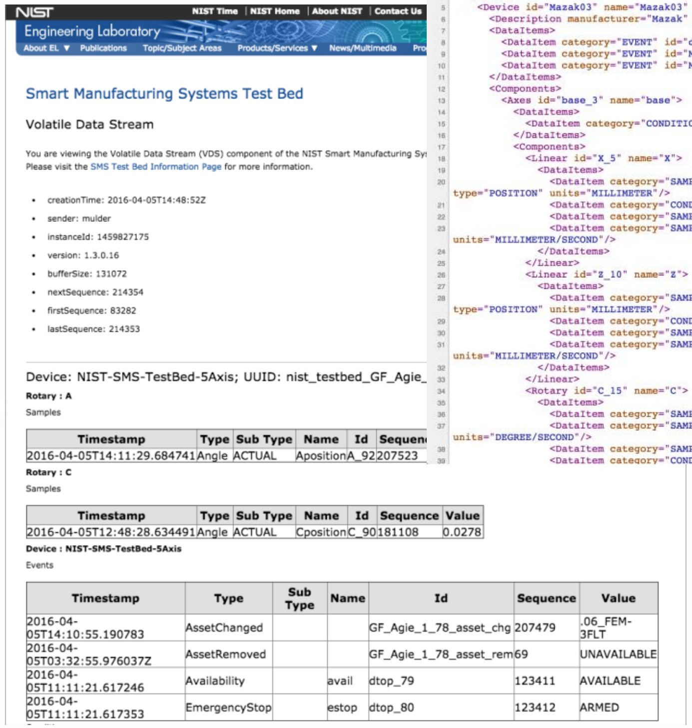
# Tier #4: Client

- Responsible for data delivery
- Consists of web applications and clients




**Access the SMS Test Bed at: https://smstestbed.nist.gov**



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## Smart Manufacturing Systems Test Bed

### Volatile Data Stream

You are viewing the Volatile Data Stream (VDS) component of the NIST Smart Manufacturing Sys
Please visit the SMS Test Bed Information Page for more information.

- creationTime: 2016-04-05T14:48:52Z
- sender: mulder
- instanceId: 1459827175
- version: 1.3.0.16
- bufferSize: 131072
- nextSequence: 214354
- firstSequence: 83282
- lastSequence: 214353

Device: NIST-SMS-TestBed-5Axis; UUID: nist_testbed_GF_Agie_

**Rotary : A**

Samples

| Timestamp | Type | Sub Type | Name | Id | Sequen |
|---|---|---|---|---|---|
| 2016-04-05T14:11:29.684741 | Angle | ACTUAL | Aposition | A_92 | 207523 |

**Rotary : C**

Samples

| Timestamp | Type | Sub Type | Name | Id | Sequence | Value |
|---|---|---|---|---|---|---|
| 2016-04-05T12:48:28.634491 | Angle | ACTUAL | Cposition | C_90 | 181108 | 0.0278 |

**Device : NIST-SMS-TestBed-5Axis**

Events

| Timestamp | Type | Sub Type | Name | Id | Sequence | Value |
|---|---|---|---|---|---|---|
| 2016-04-05T14:10:55.190783 | AssetChanged | | | GF_Agie_1_78_asset_chg | 207479 | .06_FEM-3FLT |
| 2016-04-05T03:32:55.976037Z | AssetRemoved | | | GF_Agie_1_78_asset_rem | 69 | UNAVAILABLE |
| 2016-04-05T11:11:21.617246 | Availability | | avail | dtop_79 | 123411 | AVAILABLE |
| 2016-04-05T11:11:21.617353 | EmergencyStop | | estop | dtop_80 | 123412 | ARMED |


```xml
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xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="urn:mtconnect.org:MTConnectDevices:1.3
/schemas/MTConnectDevices_1.3.xsd">
  <Header creationTime="2016-09-02T18:55:22Z" sender="mulder" instanceId="1464710885" version="1.3.0.16" assetBufferSize="1024"
assetCount="0" bufferSize="131072"/>
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    <Device id="Mazak03" name="Mazak03" uuid="mtc_adapter004">
      <Description manufacturer="Mazak" model="QTN">Mazak Quickturn - Mazak Quick Turn Nexus 300</Description>
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        <DataItem category="EVENT" id="Mazak03_asset_chg" type="ASSET_CHANGED"/>
        <DataItem category="EVENT" id="Mazak03_asset_rem" type="ASSET_REMOVED"/>
      </DataItems>
      <Components>
        <Axes id="base_3" name="base">
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            <DataItem category="CONDITION" id="base_4" name="servo_cond" type="ACTUATOR"/>
          </DataItems>
          <Components>
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              <DataItems>
                <DataItem category="SAMPLE" coordinateSystem="MACHINE" id="X_6" name="Xabs" nativeUnits="MILLIMETER" subType="ACTUAL"
type="POSITION" units="MILLIMETER"/>
                <DataItem category="CONDITION" id="X_7" name="Xtravel" type="POSITION"/>
                <DataItem category="SAMPLE" id="X_8" name="Xload" nativeUnits="PERCENT" type="LOAD" units="PERCENT"/>
                <DataItem category="SAMPLE" id="X_9" name="Xfrt" nativeUnits="MILLIMETER/SECOND" type="AXIS_FEEDRATE"
units="MILLIMETER/SECOND"/>
              </DataItems>
            </Linear>
            <Linear id="Z_10" name="Z">
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                <DataItem category="CONDITION" id="Z_12" name="Ztravel" type="POSITION"/>
                <DataItem category="SAMPLE" id="Z_13" name="Zload" nativeUnits="PERCENT" type="LOAD" units="PERCENT"/>
                <DataItem category="SAMPLE" id="Z_14" name="Zfrt" nativeUnits="MILLIMETER/SECOND" type="AXIS_FEEDRATE"
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            <Rotary id="C_15" name="C">
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units="DEGREE/SECOND"/>
                <DataItem category="SAMPLE" id="C_18" name="Cdeg" nativeUnits="DEGREE" subType="ACTUAL" type="ANGLE" units="DEGREE"/>
                <DataItem category="CONDITION" id="C_19" name="Ctravel" type="ANGLE"/>
```



M. Helu, T. Hedberg, A. Barnard Feeney (2017) Reference Architecture to Integrate Heterogeneous Manufacturing Systems for the Digital Thread. *J. Mfg. Sci. & Tech.*, 19, 191-195. DOI:10.1016/j.cirpj.2017.04.002.

# Data is the Gateway to further Insight…

**Many manufacturers – especially SMEs – believe that they understand their performance until confronted with real data**


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# New Insights by Leveraging Manufacturing Data

**Refining information**

- Detailed machine states
- Additional context to support correlation and diagnosis
- Additional context to support multiple viewpoints

**Higher-Value Use Cases**

- Predictive maintenance
- Prognostics
- Dynamic scheduling
- Business support (spare part provisions, RFPs)
- Workforce augmentation

M. Helu, B. Weiss (2016) The Current State of Sensing, Health Management, and Control for Small-to-Medium-Sized Manufacturers. *Proc. ASME MSEC 2016*, V002T04A007. DOI:10.1115/MSEC2016-8783.

# Data Contextualization

- Process of combining different types of data to provide a more complete perspective of some phenomenon
- Quality of information extracted from data depends on appropriateness of context developed during data curation
- Appropriate context depends on viewpoint

W. Z. Bernstein, T. D. Hedberg, M. Helu, A. Barnard Feeney (2017) Contextualizing Manufacturing Data for Lifecycle Decision-Making. *Intl. J. PLM*, 10(4), 326-347. DOI:10.1504/IJPLM.2017.090328.



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# Viewpoints across the Product Lifecycle

| Lifecycle Stage | Broad Focus | General Role |
|---|---|---|
| Design | Features | Define features to meet requirements of form, fit, and function of part |
| Planning | Capabilities | Organize a set of capabilities executed through different processes to create features of part |
| Manufacturing | Processes | Implement processes with maximum productivity to create features of part |
| Inspection | Characteristics | Compare characteristics of manufactured feature to its definition in design |

**(*) Context needed within each lifecycle stage may not be uniform**
**(*) Decision making tends to focus on one viewpoint in one lifecycle stage**
**(*) Decisions can impact larger portion of product lifecycle**

W. Z. Bernstein, T. D. Hedberg, M. Helu, A. Barnard Feeney (2017) Contextualizing Manufacturing Data for Lifecycle Decision-Making. *Intl. J. PLM*, 10(4), 326-347. DOI:10.1504/IJPLM.2017.090328.

# Digital Technologies Provide Opportunity!

- Growth and accessibility of IT in manufacturing:
  - Smart manufacturing
  - Digital manufacturing
  - Cloud manufacturing
  - Cyber-physical systems
  - Internet of Things
  - Industry 4.0

**(1) Interoperability across enterprise and life cycle**
**(2) Generation of actionable intelligence**
**(3) Decision-making support**

- New opportunities to advance manufacturing:
  - Improved productivity
  - Ensured first-pass success
  - Augmented workforce development
  - Reduced costs

**(1) Many solutions available**
**(2) Historically limited market penetration**
**=> Difficult to navigate breadth of options**

M. Helu, B. Weiss (2016) The Current State of Sensing, Health Management, and Control for Small-to-Medium-Sized Manufacturers. *Proc. ASME MSEC 2016*, V002T04A007. DOI:10.1115/MSEC2016-8783.

# Getting Started…

- Define use case
  - What are my requirements?
- Identify supported devices
  - What data do I have access to?
- Evaluate network infrastructure
  - How can I access and manage that data?
- Execute integration activities
  - Who will I need to support my goals?

**Connectivity is insufficient**

**Understand what you hope to accomplish!**

http://www.mtconnect.org/getting-started/

# Define use case…

**Long-term success is predicated on developing an appropriate *data management plan* that enables the *query of curated, contextualized data* collected from devices *to support identified use cases***



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# Example of Data Management Requirements

- General description:
  - Product functions
  - User characteristics
  - Operating environments
- Interfaces:
  - User
  - Hardware
  - Software
  - Communications
- Features:
  - VDS and QDR
  - Data curation
  - System administration
- Others:
  - Performance
  - Reliability
  - Availability
  - Security
  - Maintainability

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# Further Implementation Challenges

- Different data formats and data and communications protocols
- Need for process-related information to provide full context
- Large variety of equipment age and computational power
- Obsolete operating systems
- Large data volumes over large range of temporal scales
- Demanding limitations of physical environment
- Need for extensive time synchronization

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.



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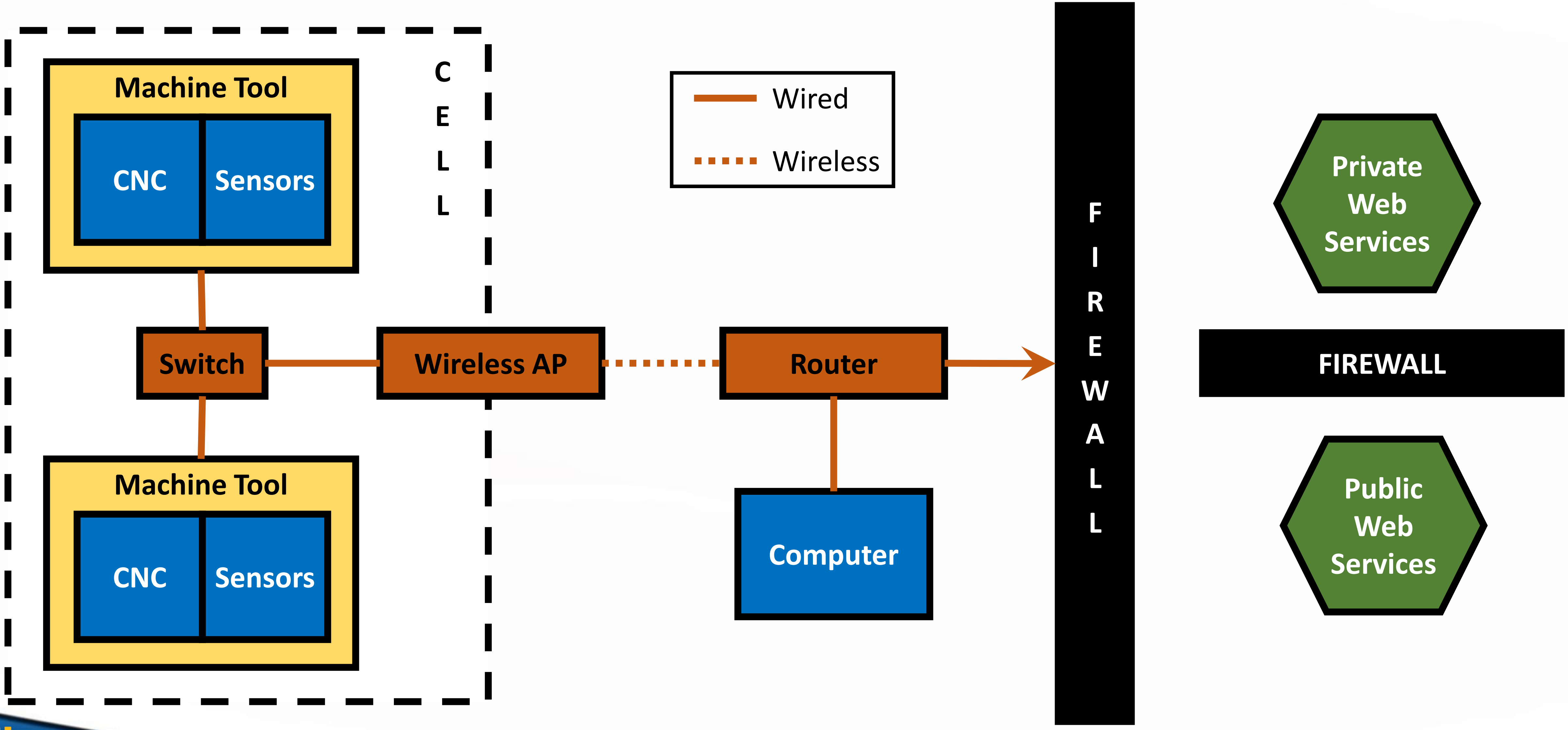
# Example of Physical Implementation



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# Example Bill of Materials

- (1x) Dell Precision T1650
- (1x) Cisco IR809 router
- (4x) Cisco Dual Radio 802.11AC AP POE
- (4x) Cisco SG100-24 24 Port Gigabit Switch
- (5x) Cisco SmartNet Service Contract (for router + APs)
- (2x) 1000-ft, 23-AWG CAT6 500 MHz UTP Solid, Riser Rater (CMR), Bulk Ethernet Bare Copper Cable
- (4x) CAT6 Plug Solid with Insert 50U, 100 pcs/bag
- (4x) RJ-45 Color-Coded Strain Relief Boots (50 pcs)
- (1x) Netgear FA411 16-Bit PCMCIA Network Card (10/100 Mbps)
- Various hardware items (e.g., double-sided tape, strain-relief tabs)

**+ Machine Tool Upgrades**
**TOTAL ~ $20-$25k**


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# Additional Resources

- General NIST SMS Test Bed Info: https://smstestbed.nist.gov/
- Documentation:
  - Design and configuration of the smart manufacturing systems test bed: https://dx.doi.org/10.6028/NIST.AMS.200-1
  - Reference architecture to integrate heterogeneous manufacturing systems for the digital thread: https://dx.doi.org/10.1016/j.cirpj.2017.04.002
  - Software requirements specification to distribute manufacturing data: https://dx.doi.org/10.6028/NIST.AMS.300-2
- Email: smstestbed@nist.gov



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# Additional Resources

- MTConnect:
  - General information: http://www.mtconnect.org/
  - Normative documentation: http://www.mtconnect.org/documents
  - Informative resources: http://www.mtconnect.org/resources
  - Open-source tools and demos: @ http://www.github.com/mtconnect
  - Reference Agent: https://github.com/mtconnect/cppagent
- MTConnectR package for analysis of MTConnect data: https://cran.r-project.org/web/packages/mtconnectR/index.html
- STEP (ISO 10303-242): https://www.iso.org/standard/57620.html
- QIF: http://qifstandards.org/

# Thank you for your kind attention!

**Moneer Helu**

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