engineering laboratory

Data Infrastructure and Management for the Digital Thread in Manufacturing

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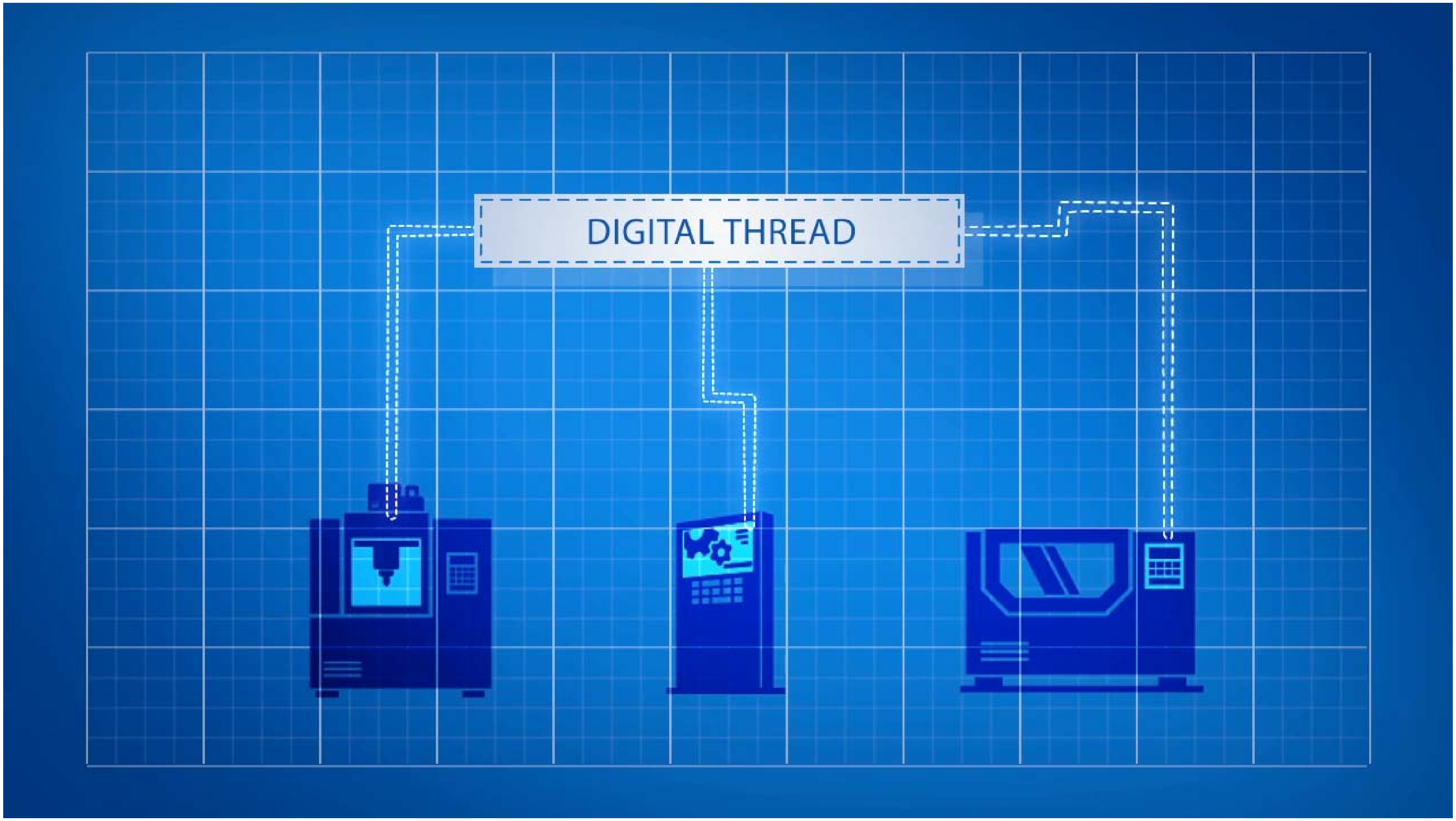
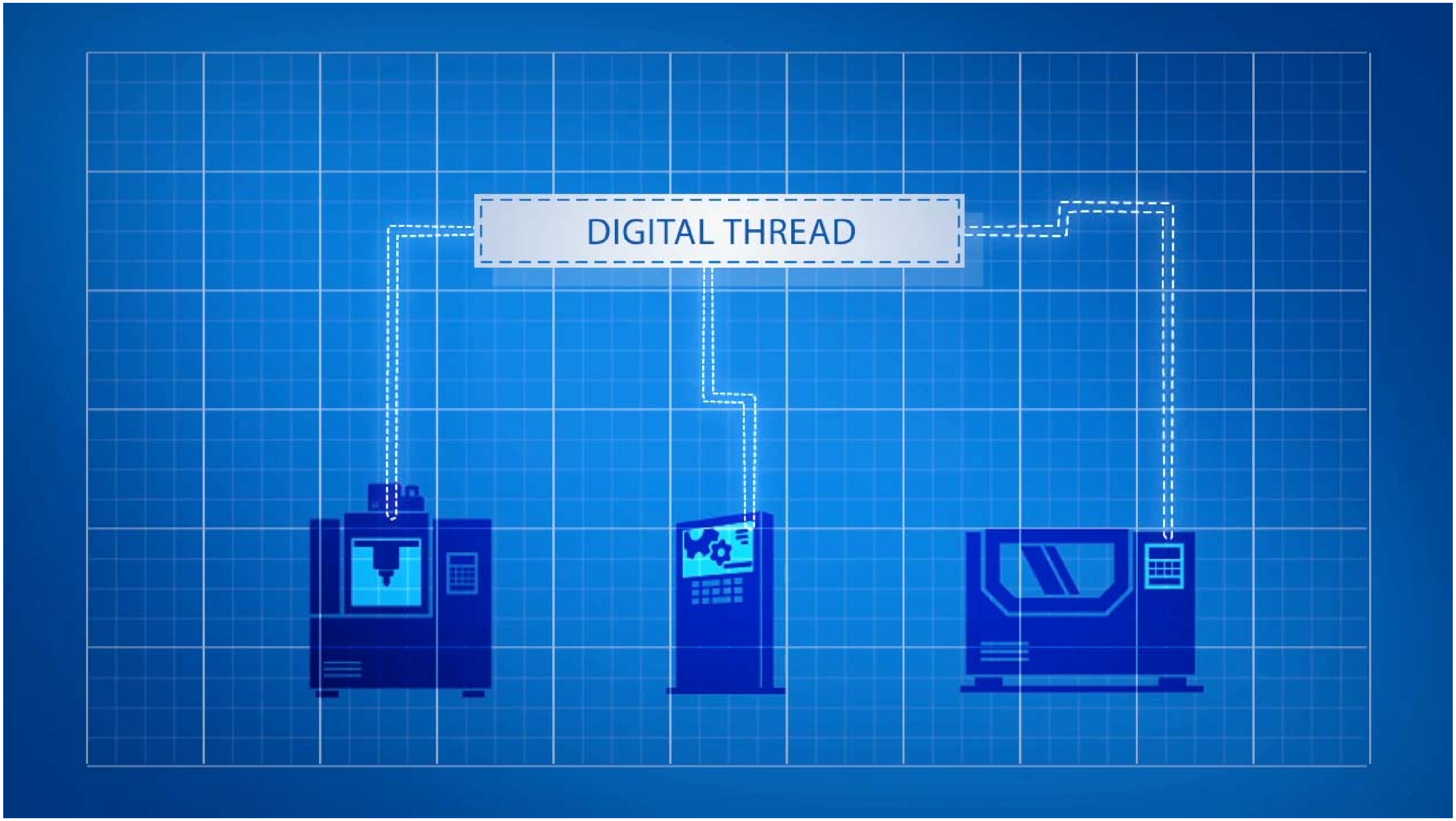
The Digital Thread



Materese, R., Gerskovic, L., Hedberg Jr, T., & Madden, J. J. (2015). The Digital Thread: Stitching Together the Next Industrial Revolution. Gaithersburg MD: National Institute of Standards and Technology. Retrieved from https://www.youtube.com/watch?v=iGtM8VGLn5M.

The Digital Thread



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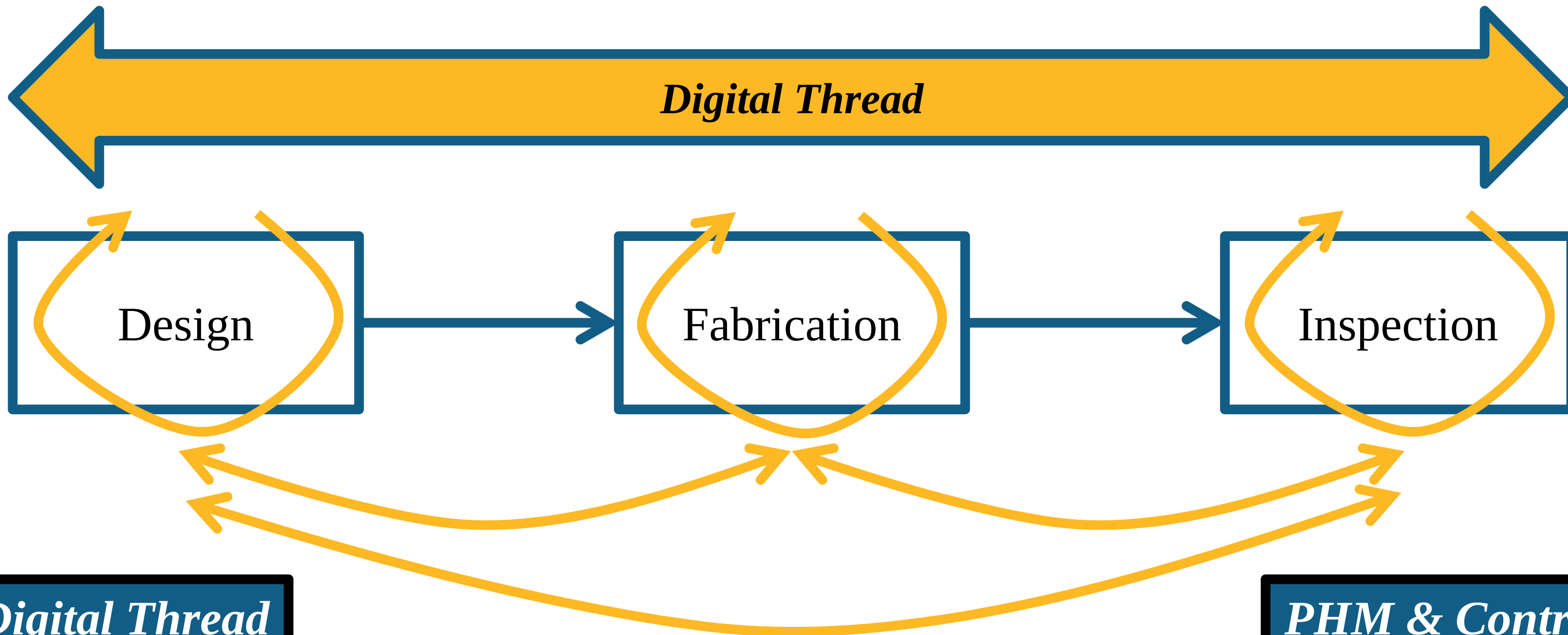
Disclaimer

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

Smart Mfg. Operations Planning and Control



Digital Thread

PHM & Control

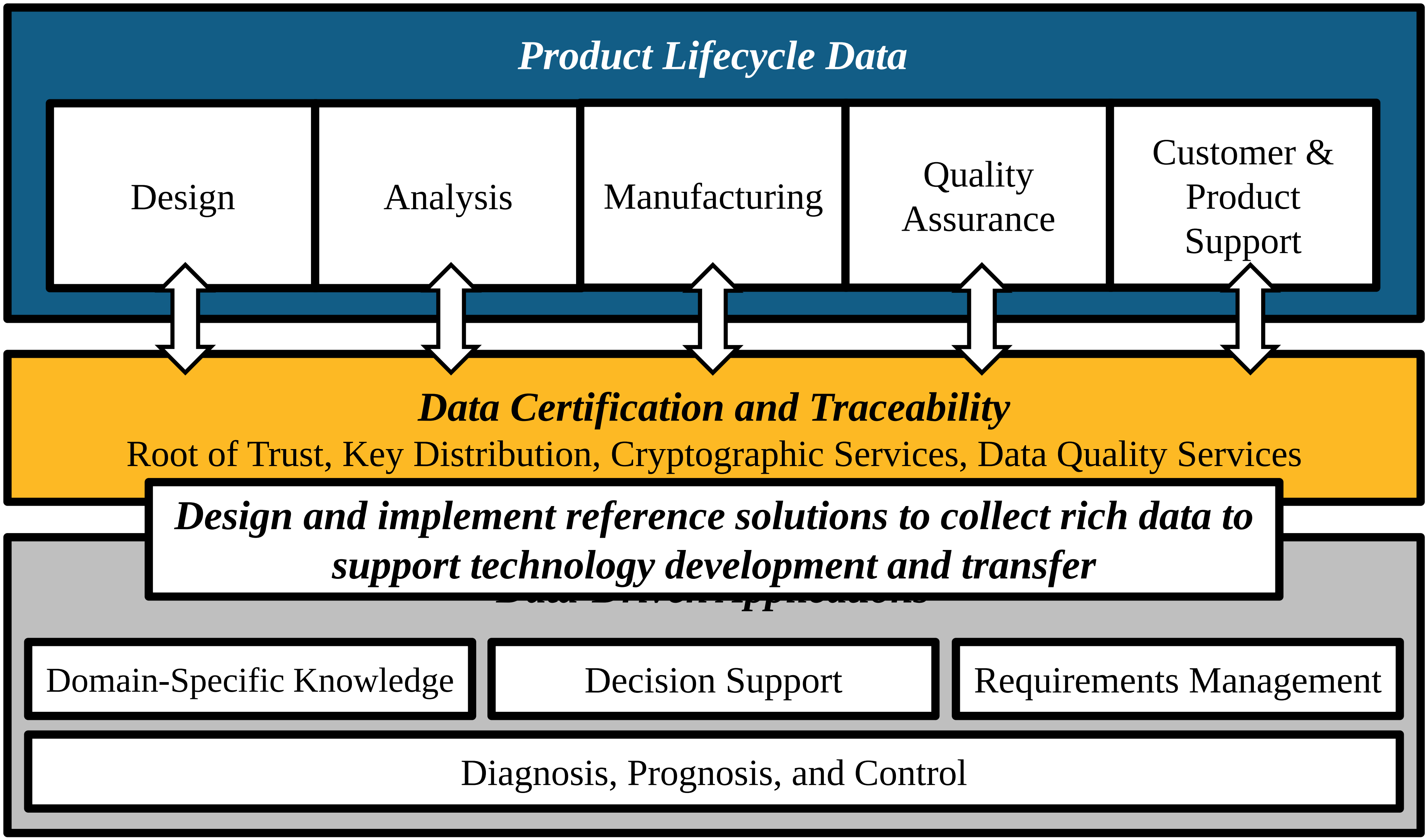
Wireless Platforms

Cybersecurity

Systems Analysis Integration

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

Lifecycle Information Framework



Hedberg, T., Barnard Feeney, A., Helu, M., Camelio, J. (2016) Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering*. 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

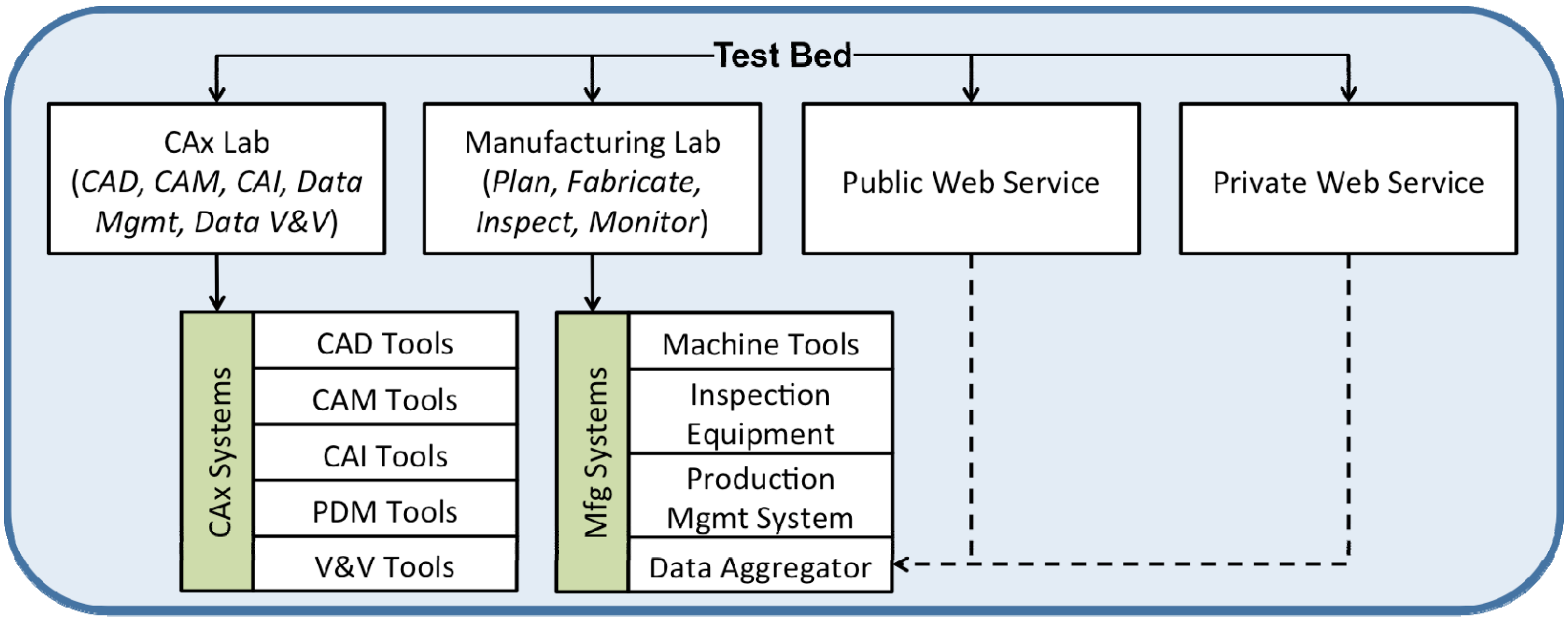
Mixture of IT and OT;
Lack of integration
across control levels

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

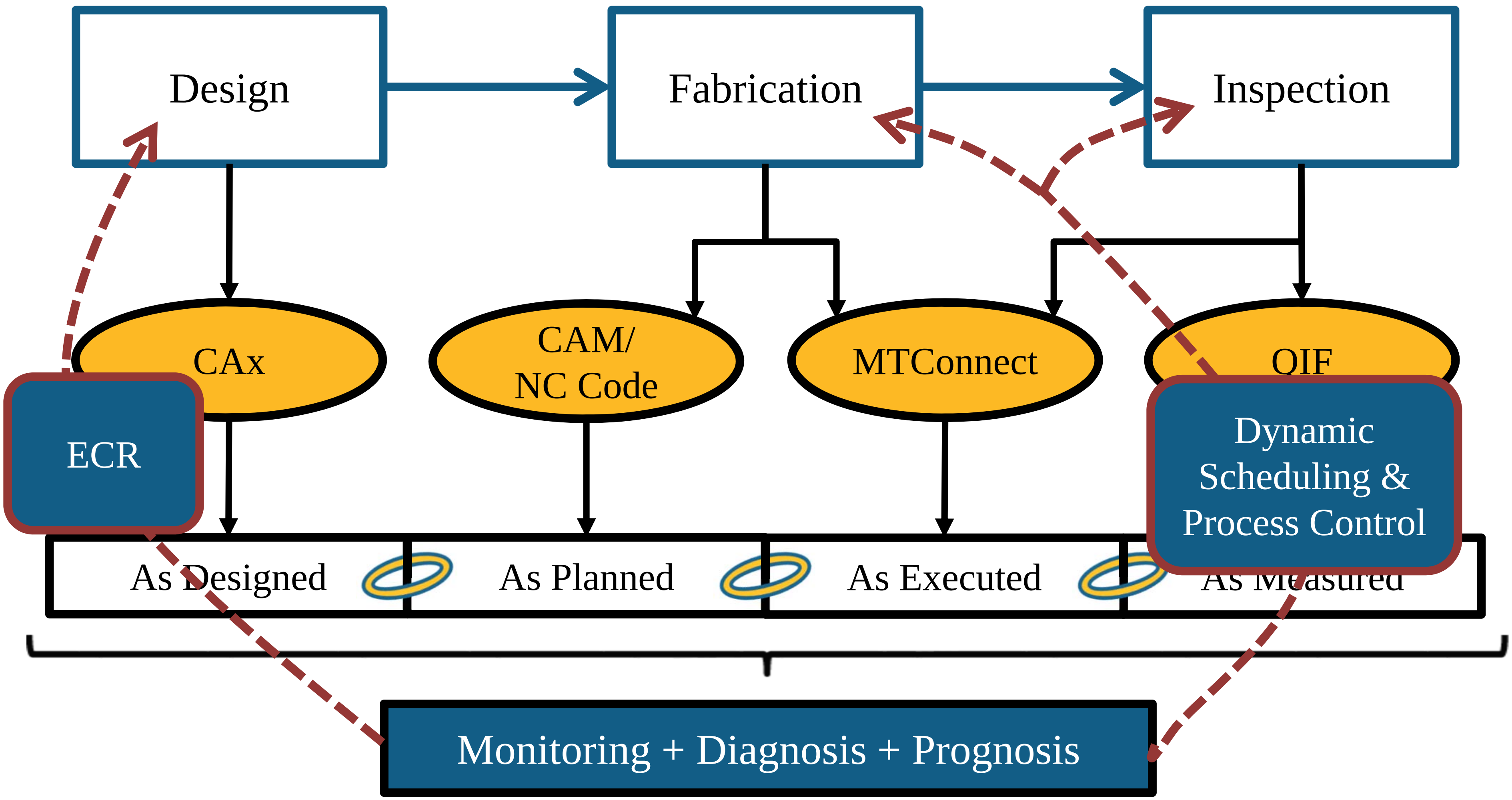
NIST Smart Mfg. Systems Test Bed

Goals:

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

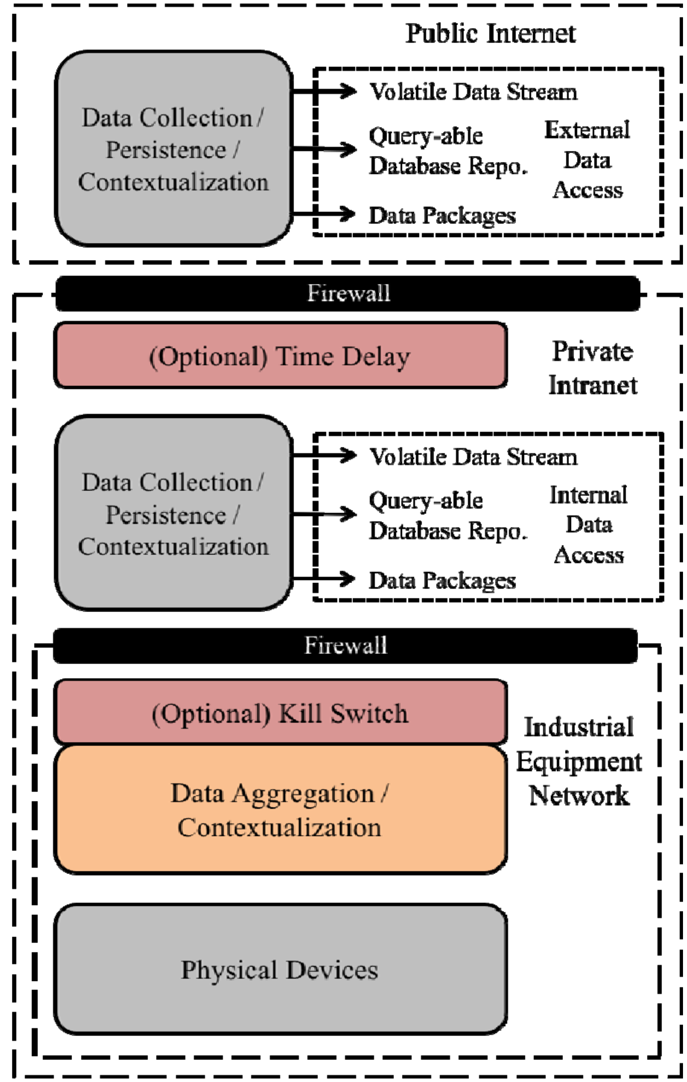


Data Collection and Aggregation



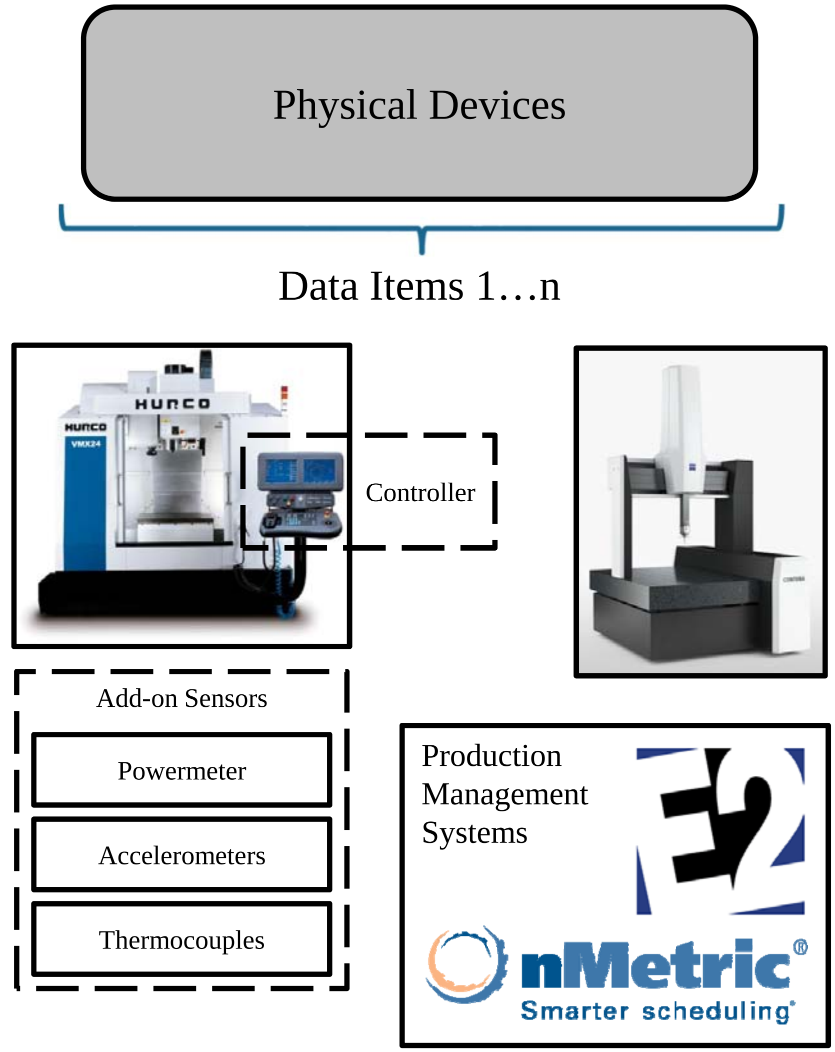
Manufacturing Data Architecture

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



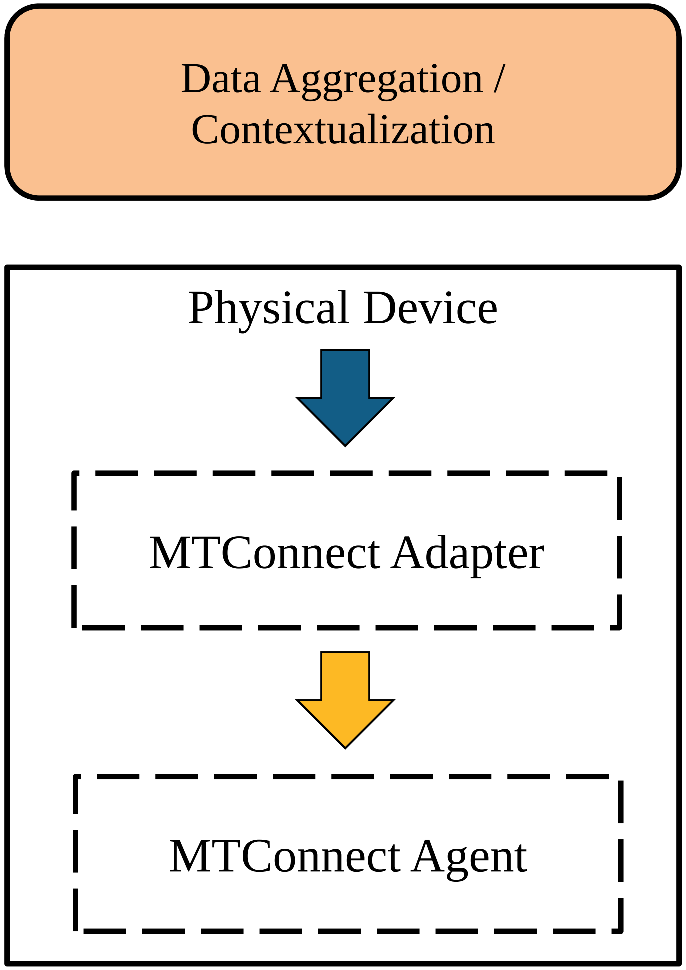
Tier #1: Services

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



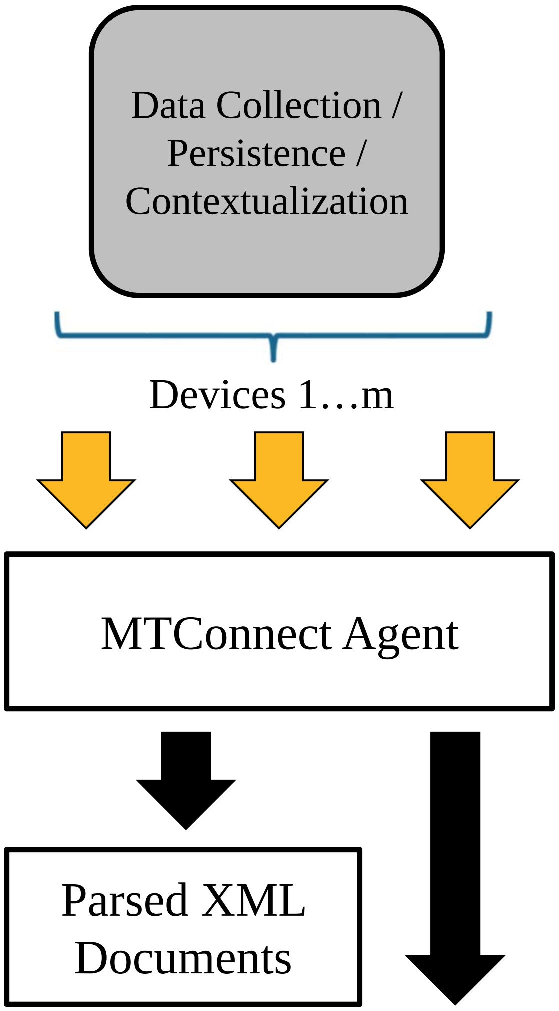
Tier #2: Aggregation

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



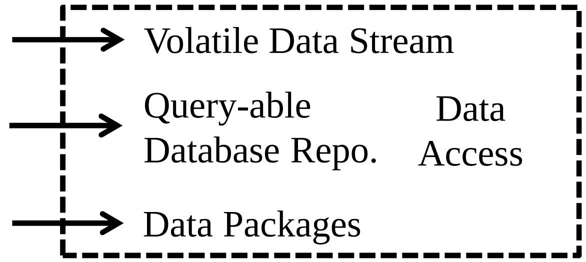
Tier #3: Delivery

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

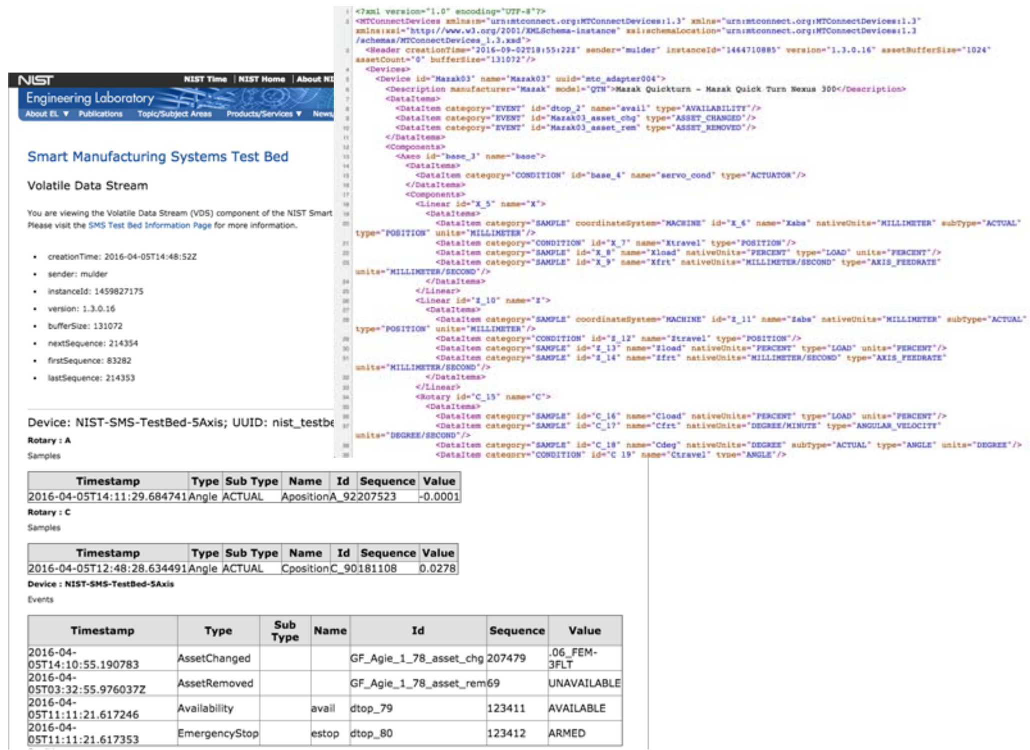


Tier #4: Client

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



VDS at:
https://smstestbed.nist.gov



Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2016-04-05T14:11:29.684741	Angle	ACTUAL	Aposition	A_92	207523	-0.0001

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

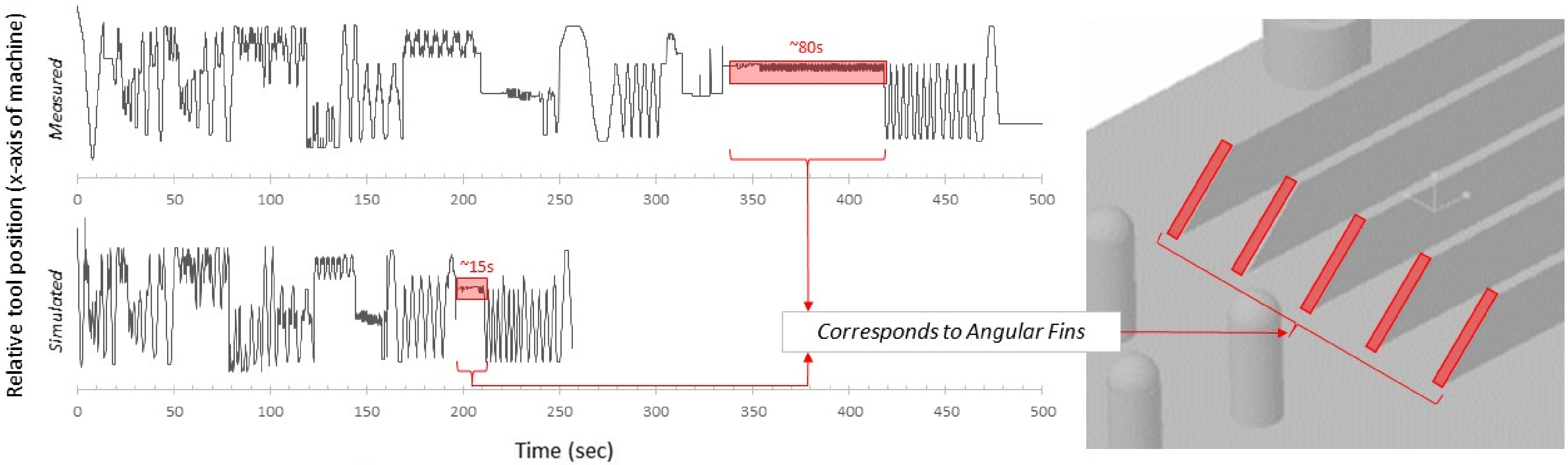
Timestamp	Type	Sub Type	Name	Id	Sequence	Value
2016-04-05T14:10:55.190783	AssetChanged			GF_Agie_1_78_asset_chg	207479	.06_FEM-3FLT
2016-04-05T03:32:55.976037Z	AssetRemoved			GF_Agie_1_78_asset_rem	69	UNAVAILABLE
2016-04-05T11:11:21.617246	Availability		avail	dtop_79	123411	AVAILABLE
2016-04-05T11:11:21.617353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

Requirements and Specifications

- 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

Demo: Monitoring Mfg. Systems

- Simulated cycle time for one feature was 15 seconds, but measured results show actual cycle time was 80 seconds
- Feed rate mismatch affects production schedule
- Need a solution to overcome impact to scheduling



In collaboration with: system insights

Retrieve models and data at: https://smstestbed.nist.gov/tdp/d2mi

Questions to Correct Mismatch

- [***Design***] Can we redesign geometry to avoid the need for toolpaths with high feed discrepancies?
- [***Planning***] Can we redesign toolpath to minimize impact of machine dynamics?
- [***Machining***] Can we enable operator to make informed decisions?
- [***Inspection***] Can we use information to identify areas for more detailed measurement?

What is the correct question to answer?

How to determine correct solution?

- **<u>Goal</u>:** Determine the best course of action to remedy production scheduling issues
- **<u>Need</u>:** Root cause of feed mismatch
- **<u>Solution</u>:** Integrate multiple data sources from systems across the product lifecycle to determine causation using data analytics

Available Data

- Design model data in native and STEP standard format (***as designed***)
- Milling program as NC code in ISO 6983 standard format (***as planned***)
- Manufacturing execution data in MTConnect standard format (***as executed***)
- Inspection data in QIF standard format (***as inspected***)

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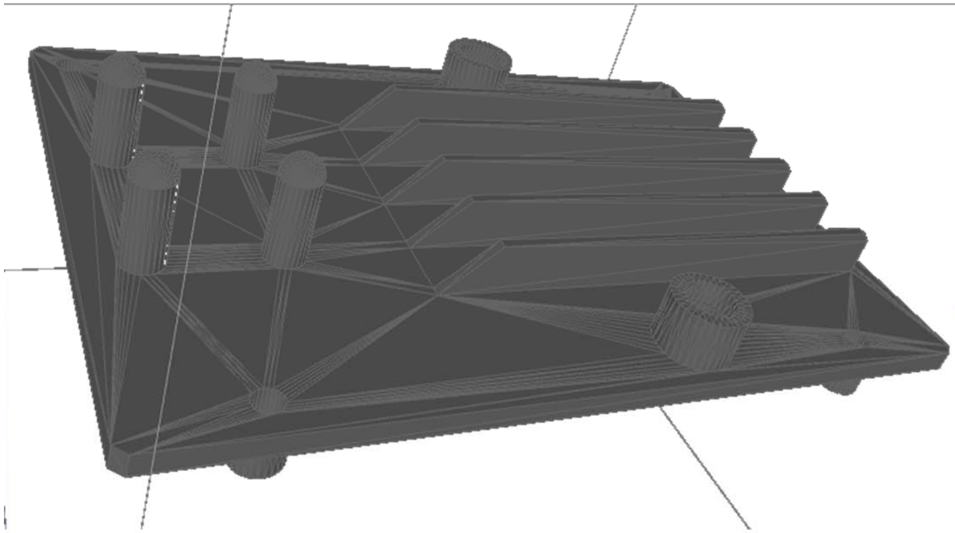
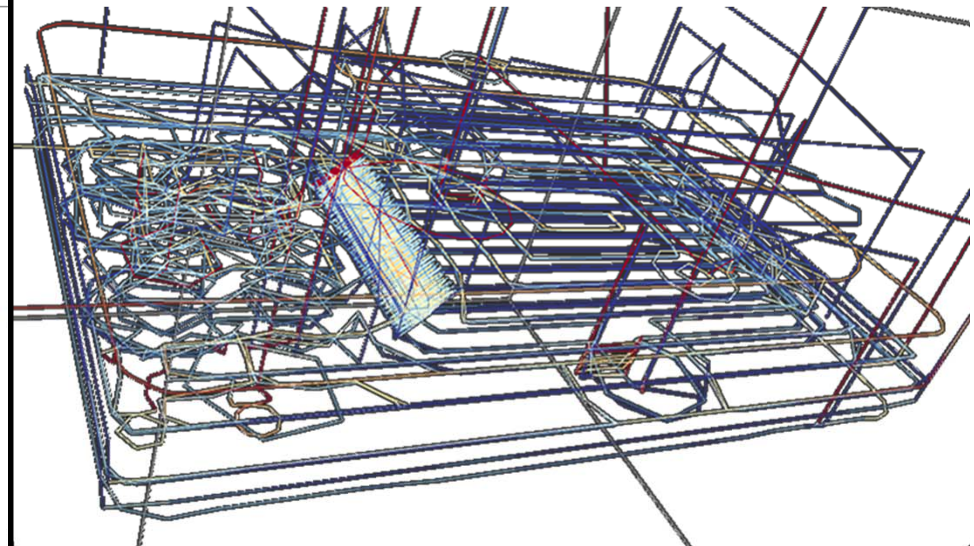
Step 1: Present and Represent Activities

Design Data



```
... ...
#131=DIRECTION(' ',(1.,0.,0.));
#136=AXIS2_PLACEMENT_3D(' ',#126,#121,#131);
#141=PLANE('',#136);
#146=CARTESIAN_POINT(' ',(-8.361367154208E-16...
#151=DIRECTION(' ',(1.087705058168E-16,1.,0.));
#156=VECTOR(' ',#151,1.);
#161=LINE('',#146,#156);
#166=CARTESIAN_POINT(' ',(-8.361367154208E-16...
#167=VERTEX_POINT(' ',#166);
... ...
```

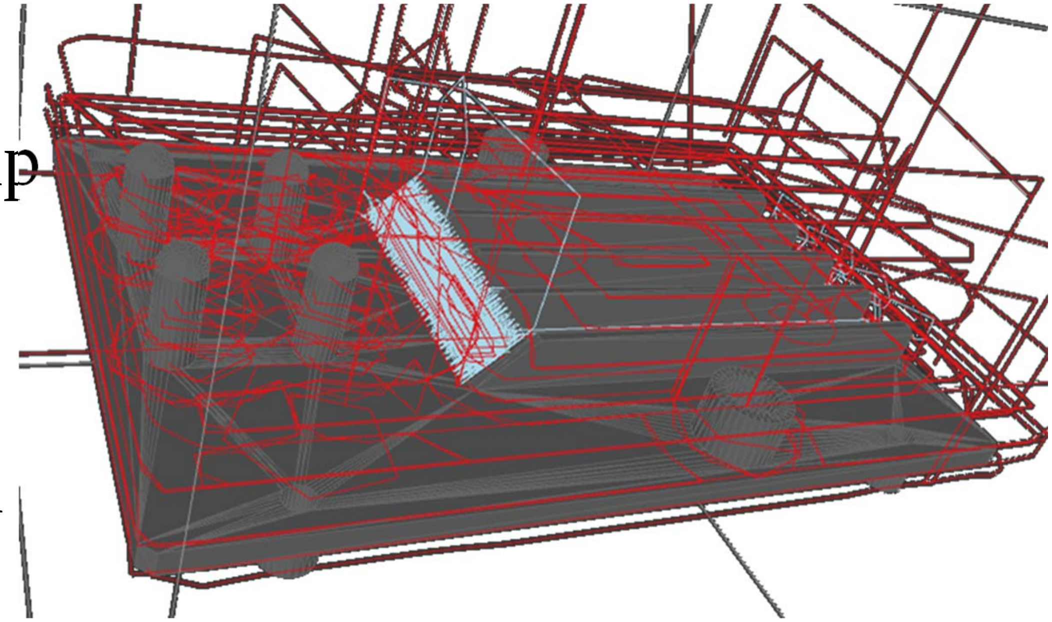
Manufacturing Data



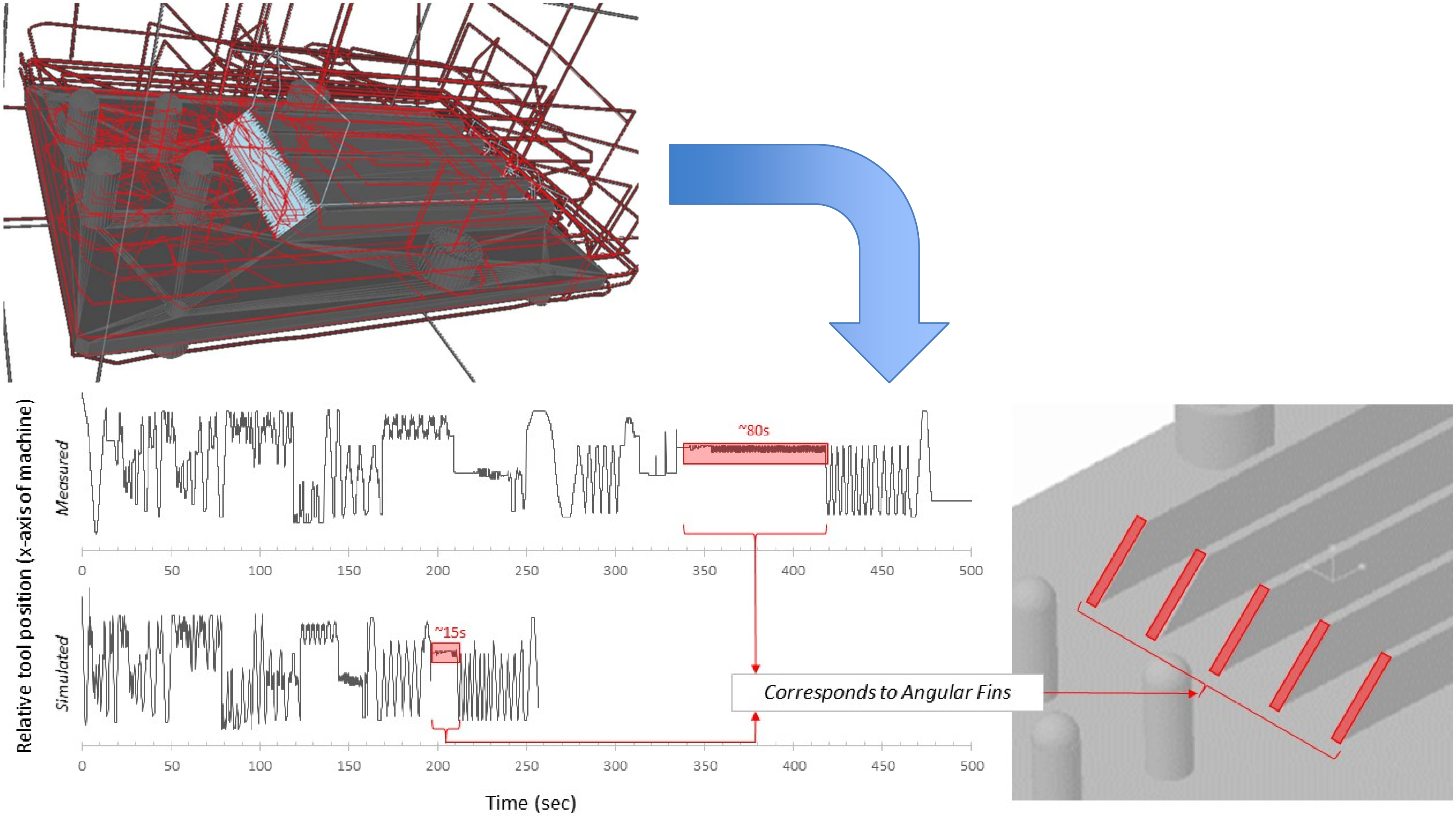
```
... ...
2016-05-09T11:46:51.456188Z|path_pos|15.0998...
2016-05-09T11:46:51.608005Z|path_pos|15.0998...
2016-05-09T11:46:51.752206Z|path_pos|15.0998...
2016-05-09T11:46:52.040056Z|path_pos|15.0998...
2016-05-09T11:46:52.040278Z|Cposition|359.9848
2016-05-09T11:46:52.184104Z|Cposition|359.9847
2016-05-09T11:46:52.616003Z|path_pos|15.0998...
2016-05-09T11:46:52.616184Z|Yposition|-37.80295
2016-05-09T11:46:52.760205Z|path_pos|15.0998...
... ...
```

Step 2: Apply Data Analytics

- Overlay the as designed, as planned, and as executed data
- Investigate the relationship of each "feature" across the linked data
- Determine causations and correlations of issues



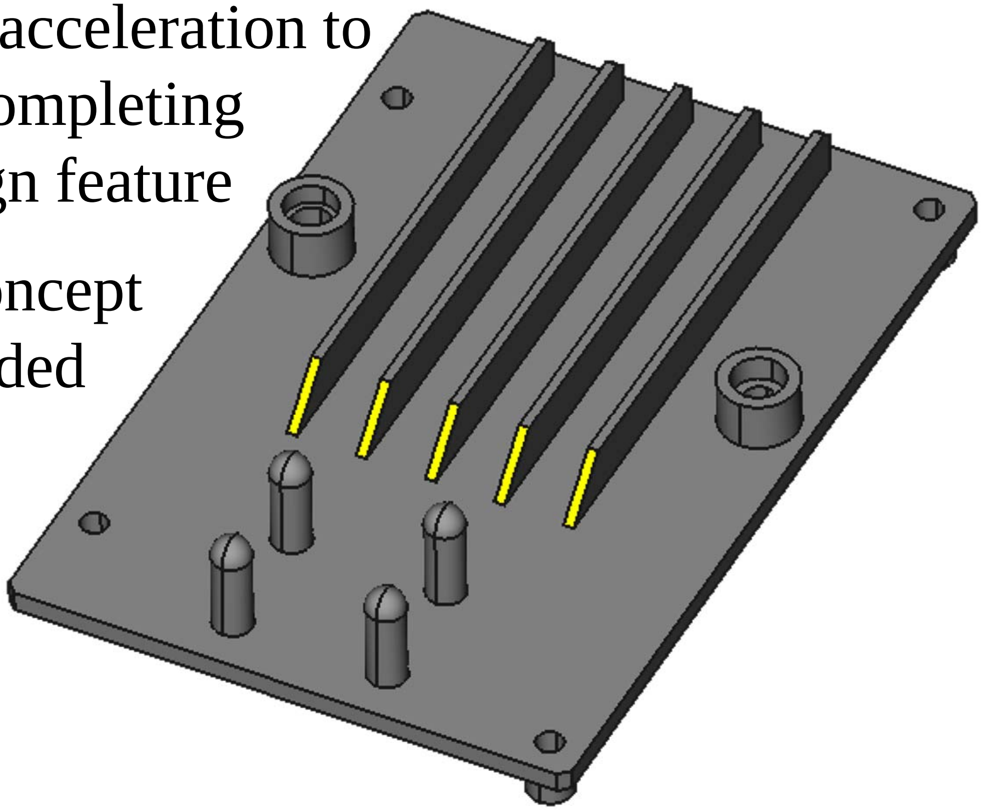
Step 3: Generate Results



Feng, S. C., Bernstein, W. Z., Hedberg Jr, T., & Barnard Feeney, A. (Under Review). Towards Knowledge Management for Smart Manufacturing. *Journal of Computing and Information Science in Engineering*.

Step 4: Build Knowledge

- **<u>Cause</u>:** Machine never reached planned feed rate
  - Height of the design feature (i.e., chamfers) is small
  - Machine cannot complete acceleration to planned feed rate before completing the fabrication of the design feature
  - Design based on legacy concept and design feature not needed in this design
- **<u>Correlation</u>:** Design, Planning, and Program defects



Step 5: Affect Change

- **Short-term (program)**: Enable operator to make educated decisions to override the planned program to speed machining
- **Mid-term (planning)**: Rework production schedule and routing to compensate for longer than expected fabrication time
- **Long-term (design)**: Redesign part to remove legacy design artifacts and optimize the design for manufacturing

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Summary

- Digital thread has potential to improve overall performance of product design and manufacture
- Substantial implementation effort needed to achieve promise of digital thread
- NIST Smart Manufacturing Systems Test Bed enables development of digital thread:
  - Data available @ https://smstestbed.nist.gov/
  - Documentation to be released
  - Data-driven applications forthcoming

Grand Opening:
MFG Day, Oct 7th

Questions?

Thank you for your kind attention!

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More information at: https://smstestbed.nist.gov/

To receive updates: smstestbed@nist.gov

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