MTConnect Testbed Workshop

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Engineering Laboratory

National Institute of Standards and Technology

Smart Manufacturing Experience

April 30 – May 2, 2018 | Boston Convention Center | Boston, MA

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

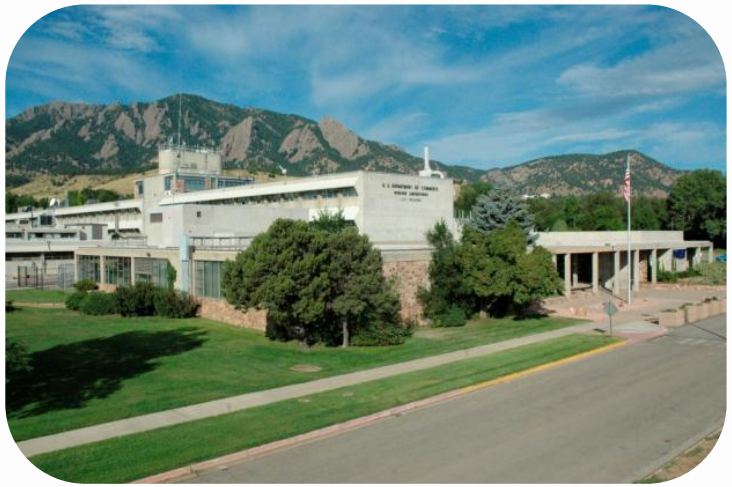
Workshop Agenda

1. Intro to NIST SMS Test Bed [15 min]
2. Why do we need data? [15 min]
3. Install virtual machine [15 min]
4. How can we collect data from machines? [30 min]
5. Break [10 min]
6. Exercise: Collecting manufacturing data [45 min]
7. Exercise: Curating manufacturing data [45 min]
8. Break [10 min]
9. Exercise: Querying manufacturing data [45 min]
10. Workshop close-out [10 min]

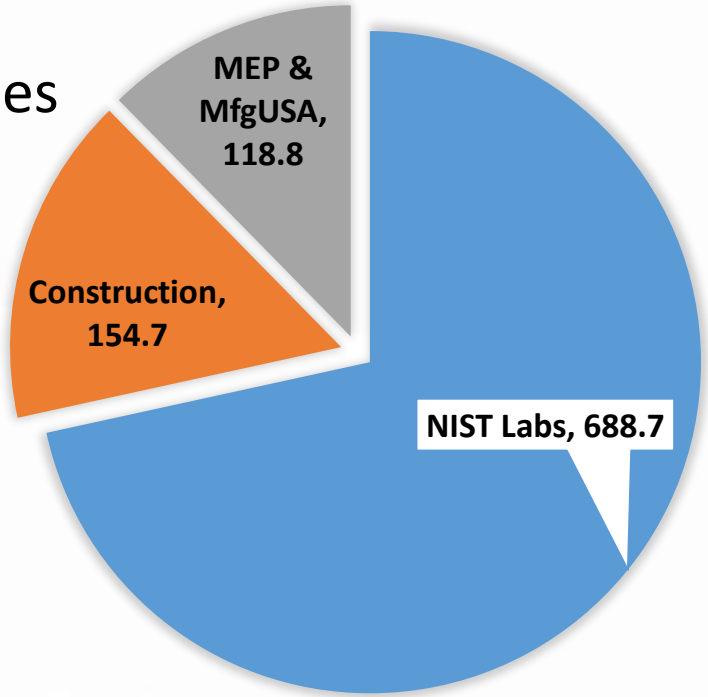
NIST: Basic Stats and Facts

- Major assets
  - ~ 3,000 employees
  - ~ 2,700 associates and facilities users
  - ~ 1,200 field staff in partner organizations
- Four Main Programs:
  - Operating Unit Laboratories
  - Manufacturing Extension Partnership
  - Baldridge Performance Excellence Program
  - Manufacturing USA
- External collaborative institutes

Gaithersburg Campus



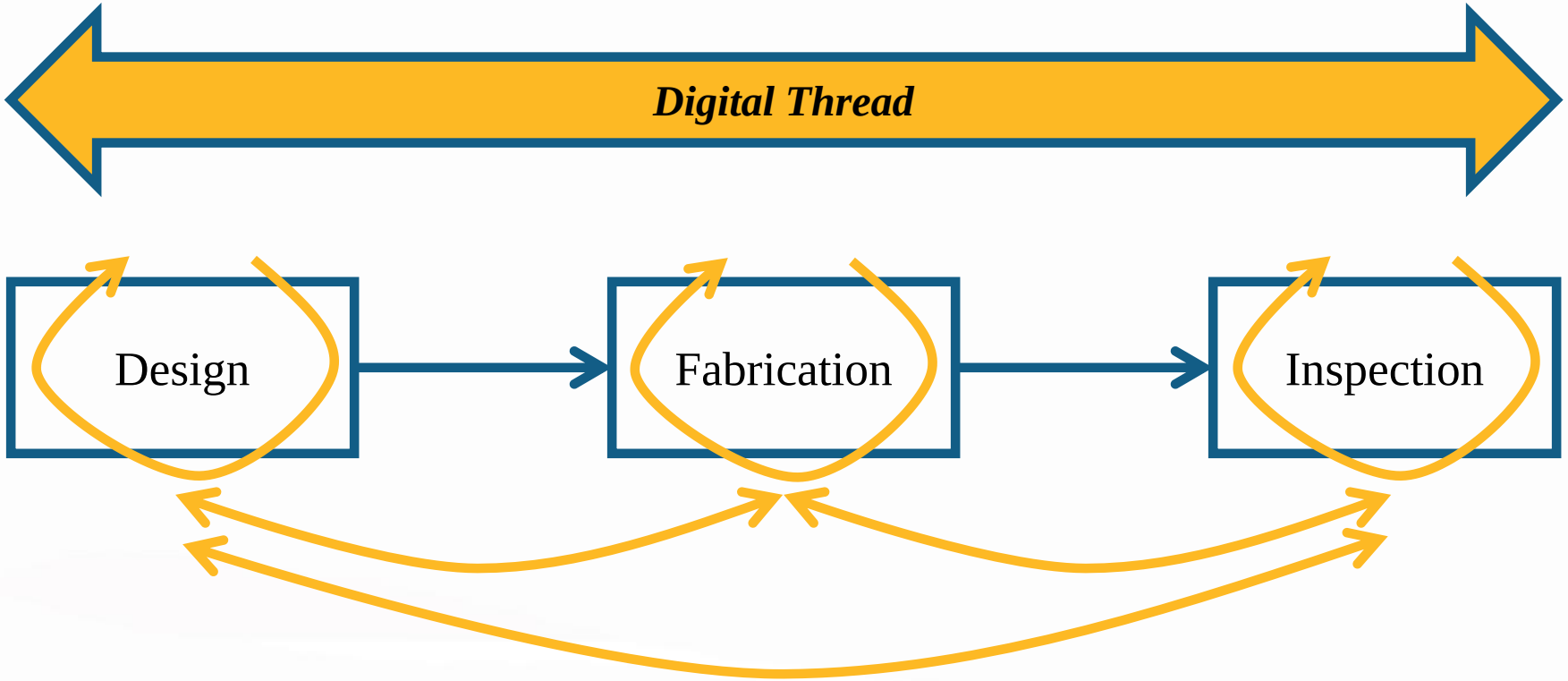
Boulder Campus



FY 2017 ANNUALIZED CR $962.2M

Introduction to NIST Smart Manufacturing Systems (SMS) Test Bed

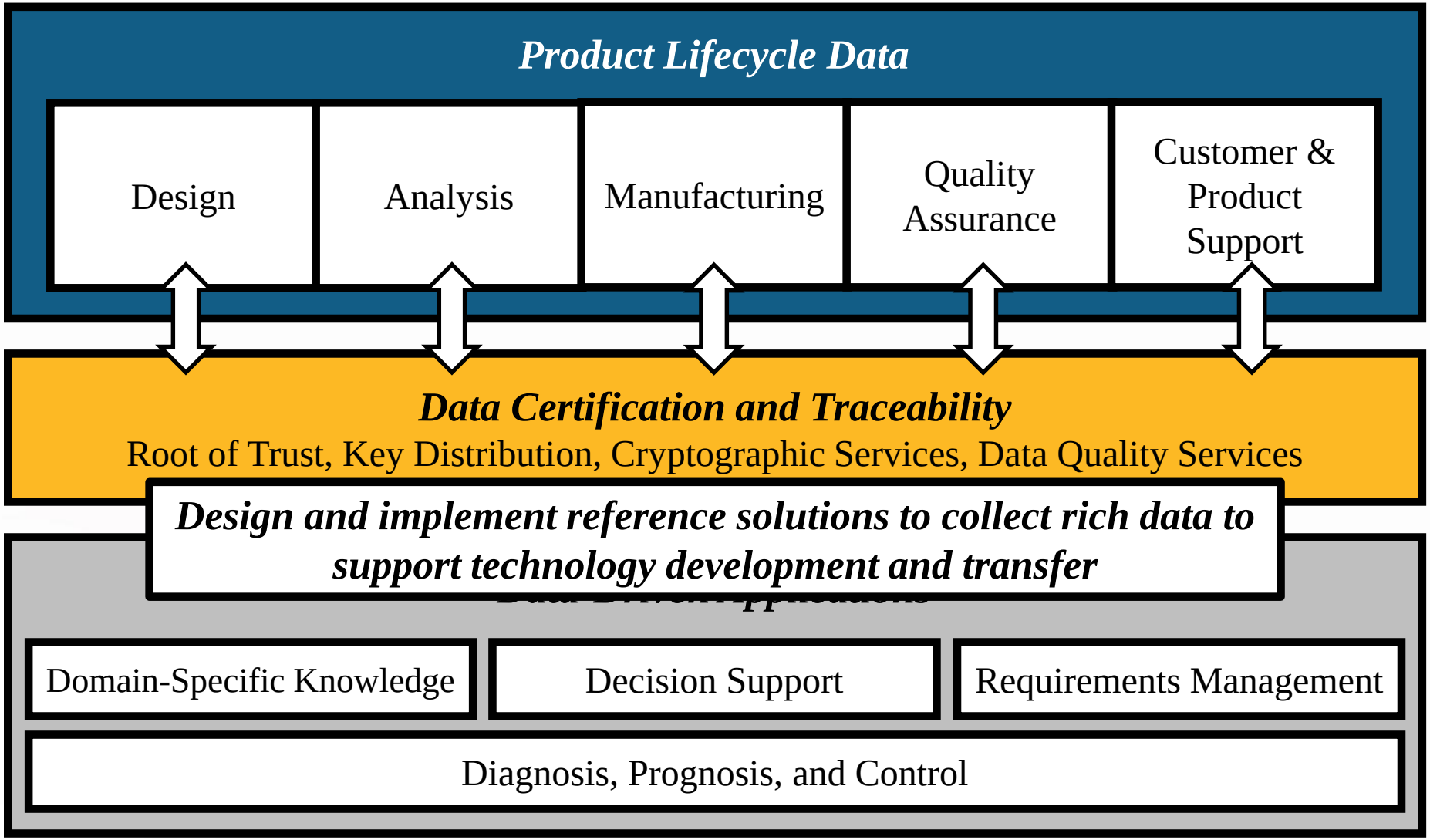
Motivation



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

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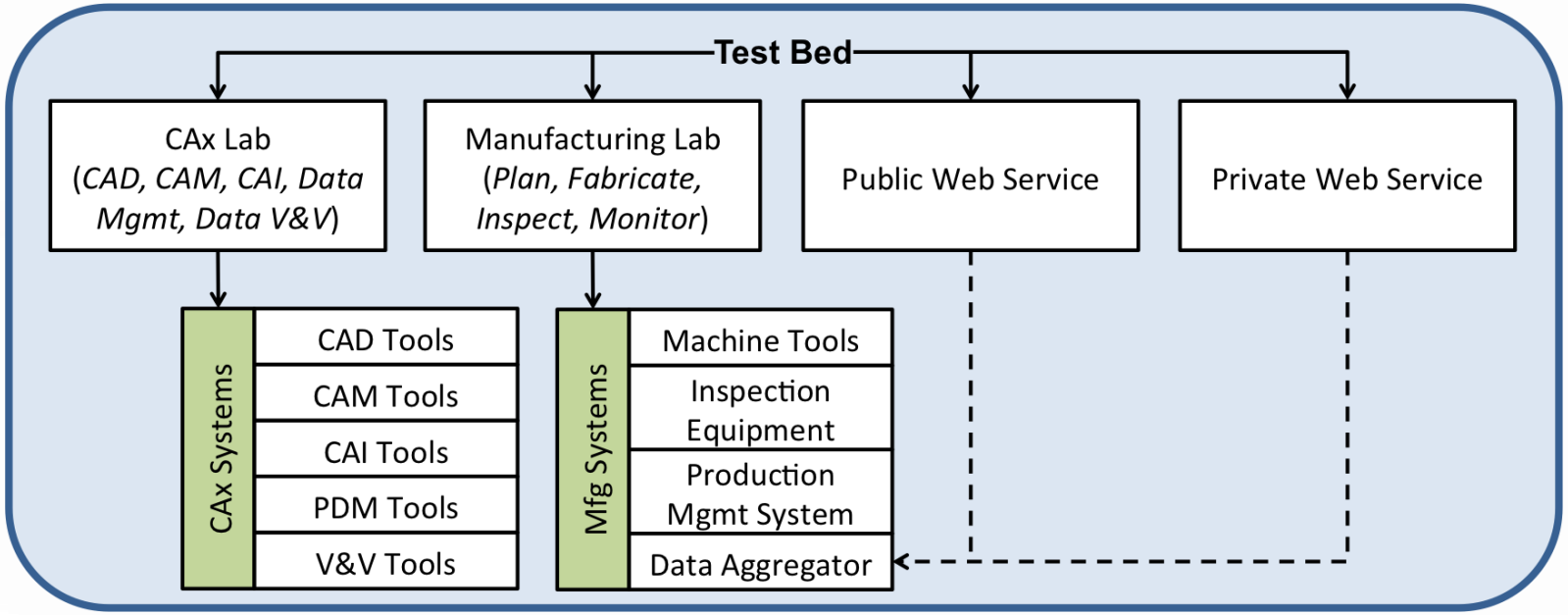
NIST Smart Mfg. Systems Test Bed

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



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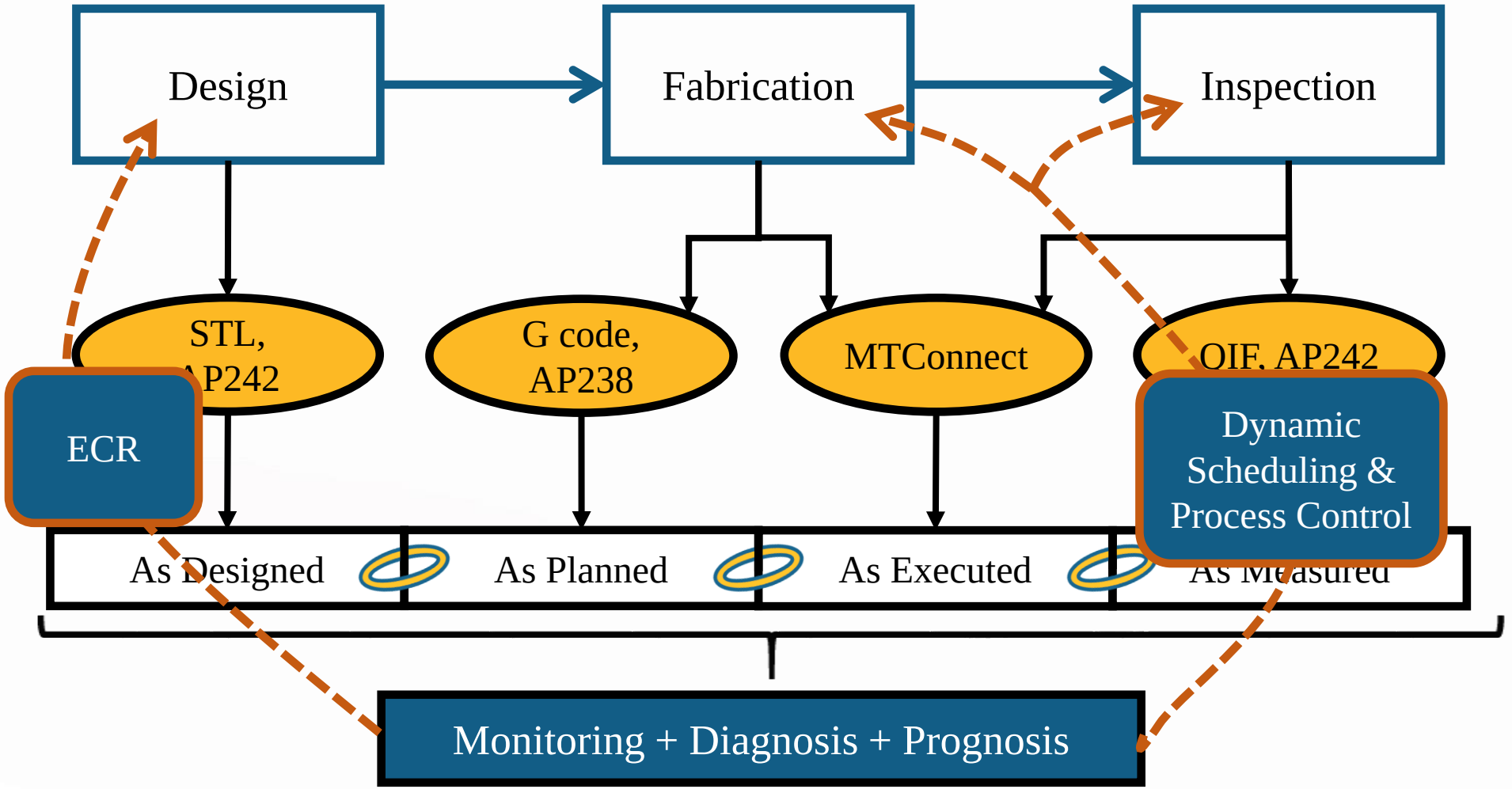
Data Collection and Aggregation



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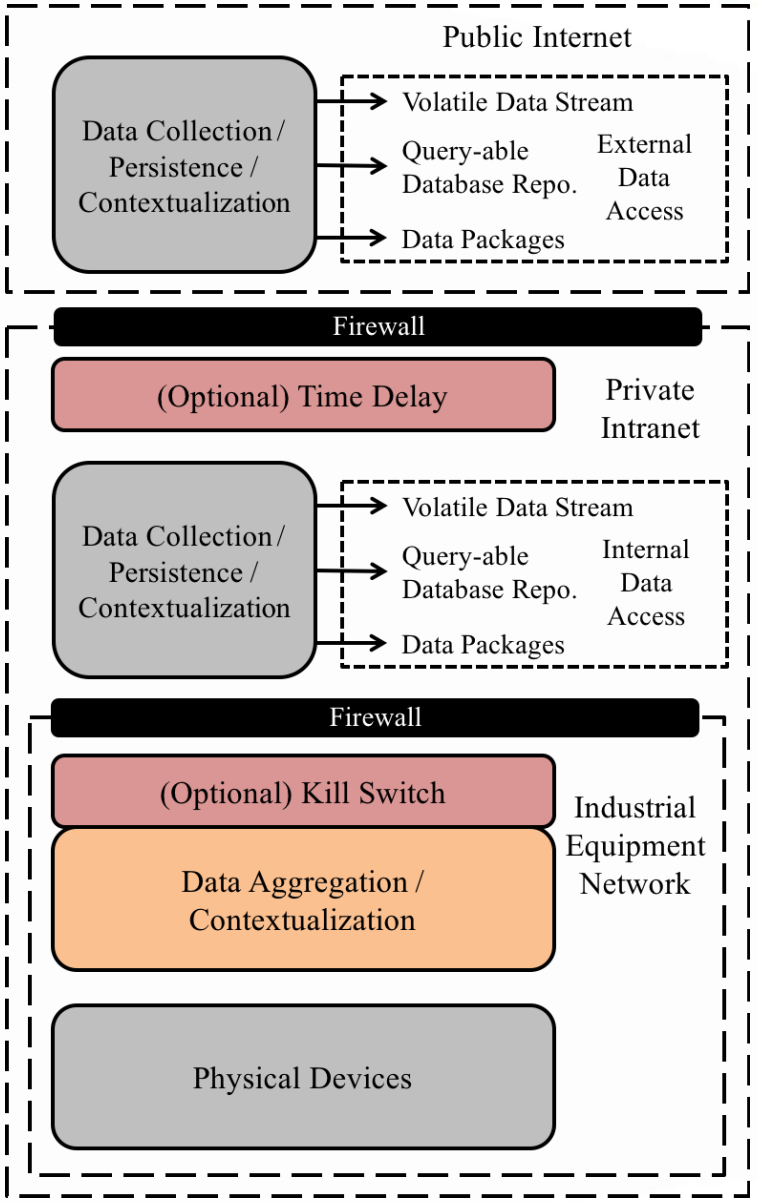
Manufacturing Data Architecture

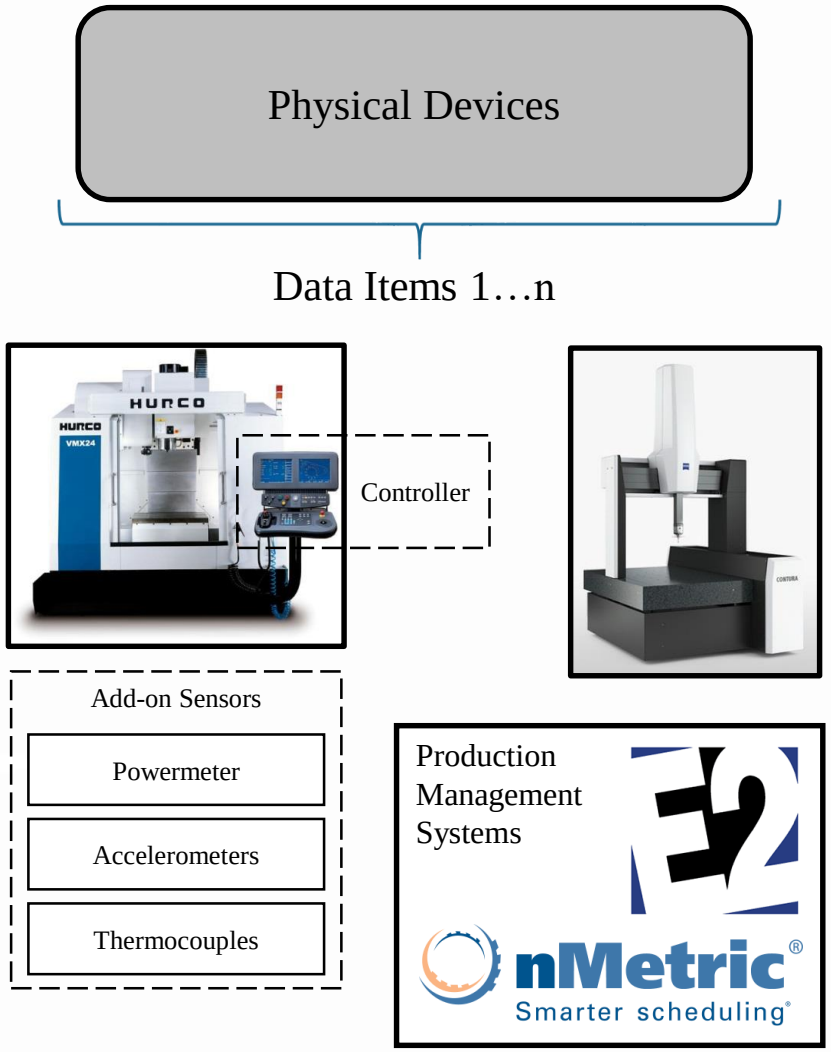
- Designed as a four-tier architecture
- Implemented across three networks
- Provides segregated access to internal and external clients



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.

Tier #1: Services

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



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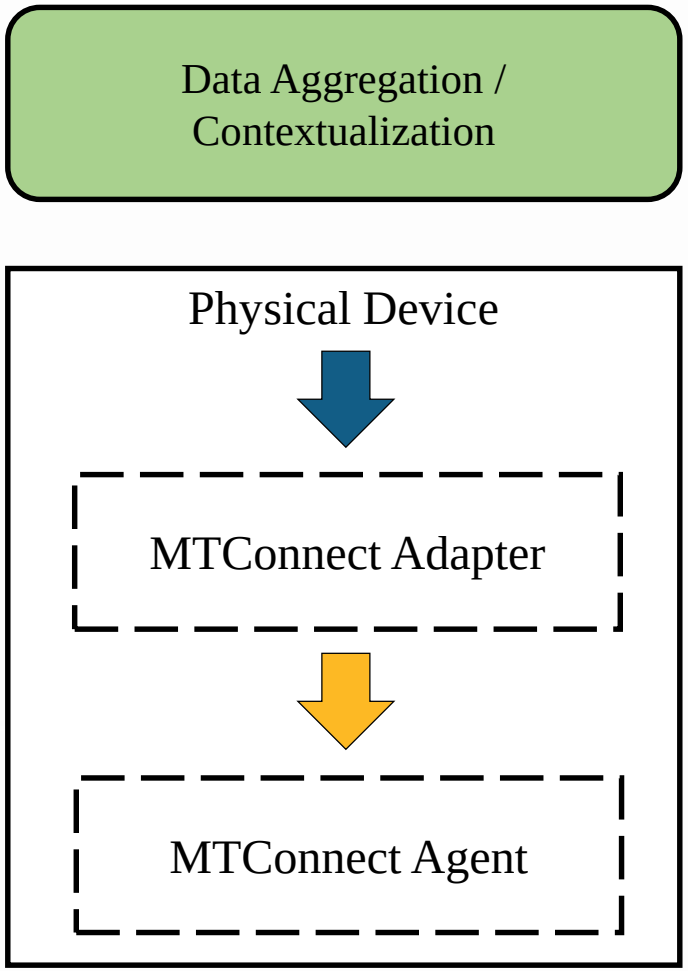
Tier #2: Aggregation

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



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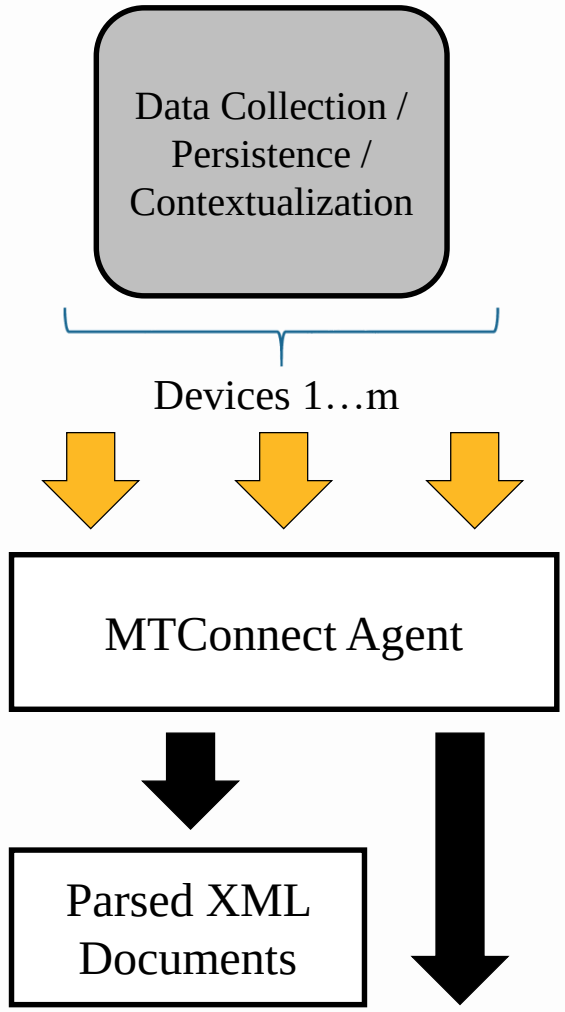
Tier #3: Delivery

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



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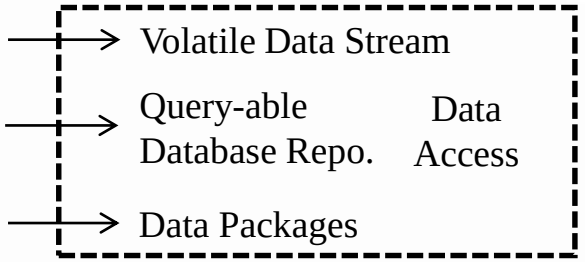
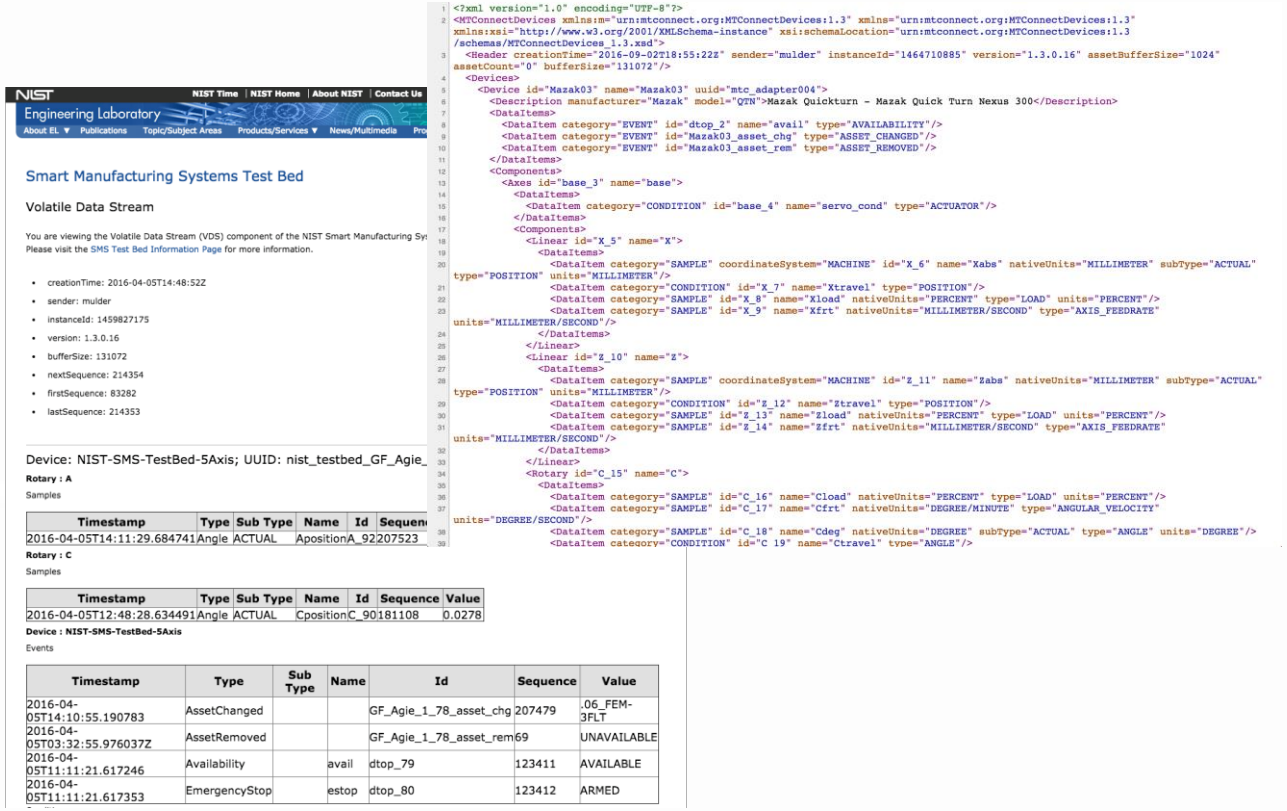
Tier #4: Client

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



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



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Why does manufacturing need data?

Assessing Performance of Manufacturing Systems

Common Metrics

- Gross margin
- Basic utilization
- Value-added time
- Part-program conformance
- Estimation conformance
- Process efficiency
- OEE

Common Tools

- Dashboards
- Analysis/Reporting
- Operator feedback
- Estimation
- Preventative Maintenance
- Tool management
- Scheduling and routing

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 is the Gateway to further Insight…

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

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 (spart part provisions, RFPs)
- Workforce augmentation

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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.

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

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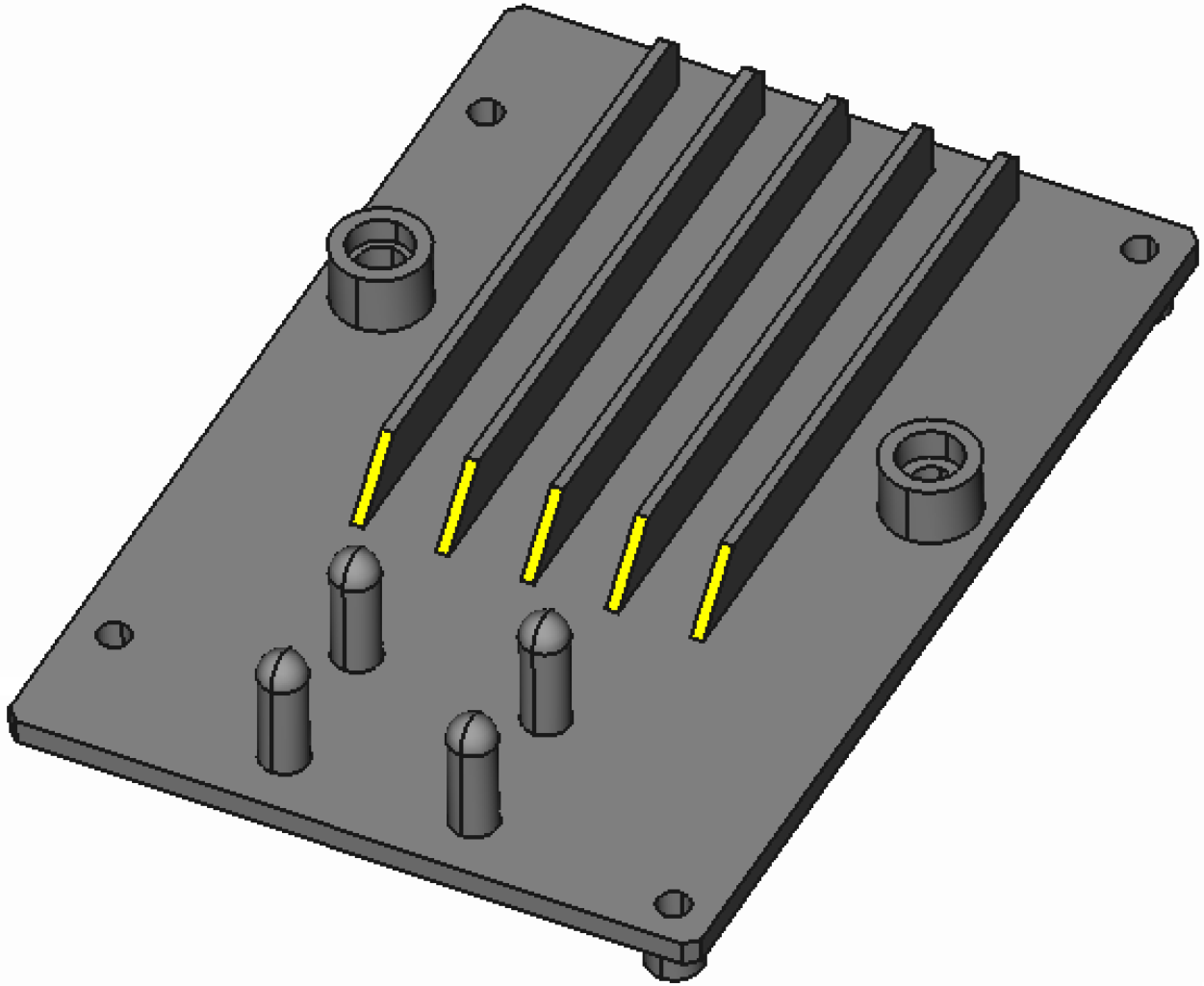
Demonstration: Heat Sink for Avionics Card

- **Issue:** Production schedule impacted by feed rate mismatch
- **Goal:** Determine root cause and appropriate solution
- **Approach:** Collect and merge data for analysis



In collaboration with: VIMANA

S. C. Feng, W. Z. Bernstein, T. Hedberg, A. Barnard Feeney (2017) Toward Knowledge Management for Smart Manufacturing. *J. Computing & Info. Sci. in Eng.* 17(3), 031016. DOI:10.1115/1.4037178.

Potential Solutions

- [***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?
- [***Production***] Can we use process simulation to account for machine dynamics during production scheduling?
- [***Inspection***] Can we use information to identify areas for more detailed measurement?

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Data Sources

- [***As Designed***] Design model data in native and ***STEP*** standard format
- [***As Planned***] Milling program as NC code in ***ISO 6983*** standard format
- [***As Executed***] Manufacturing execution data in ***MTConnect*** standard format
- [***As Inspected***] Inspection data in ***QIF*** standard format

Standard data formats promote interoperability

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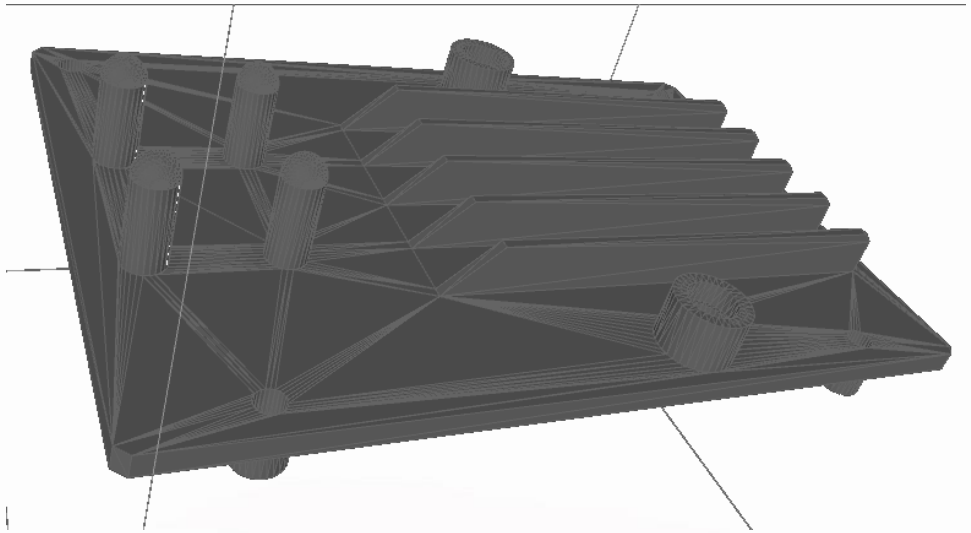
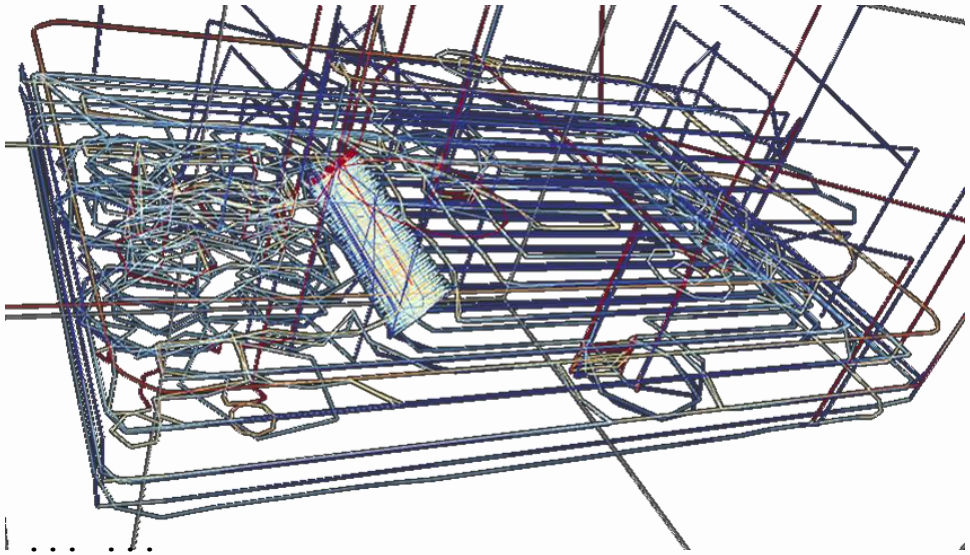
Present and Represent Activities

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...
... ...
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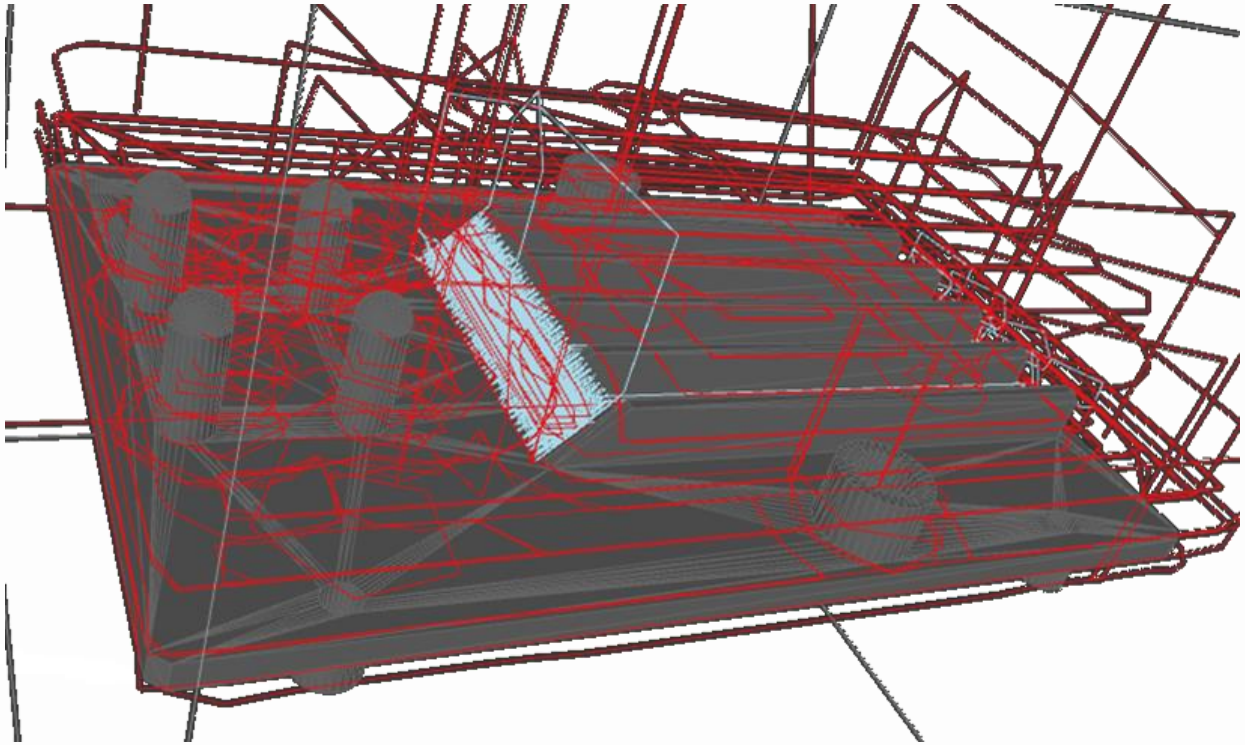
Link Data and Apply Analytics

- Overlay the as designed, as planned, and as executed data
- Study linked data across each feature
- Determine causes and correlations of issues



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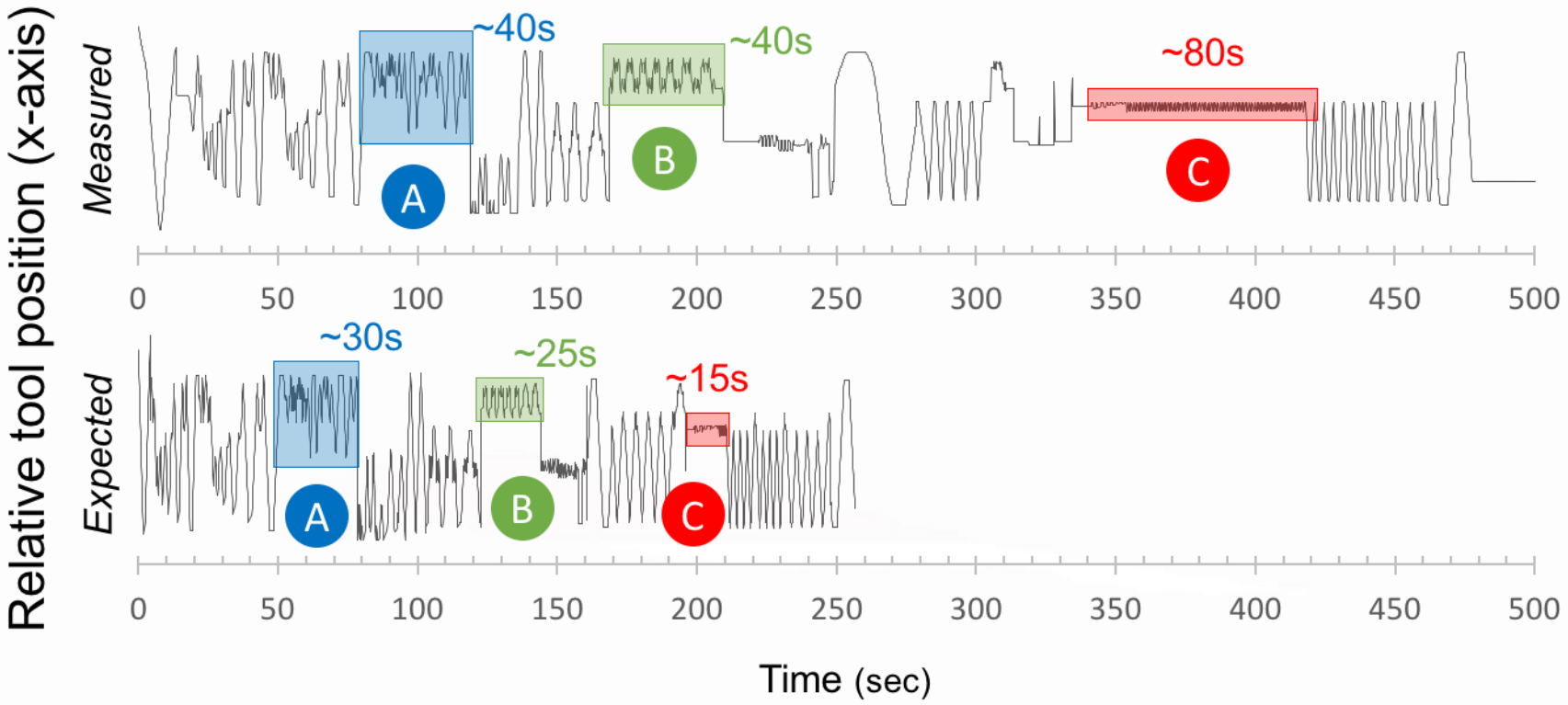
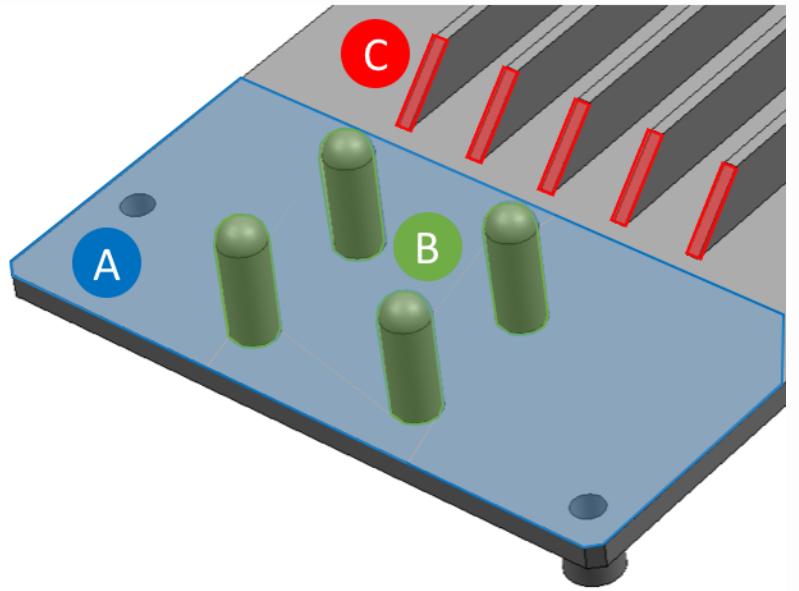
Generate Results





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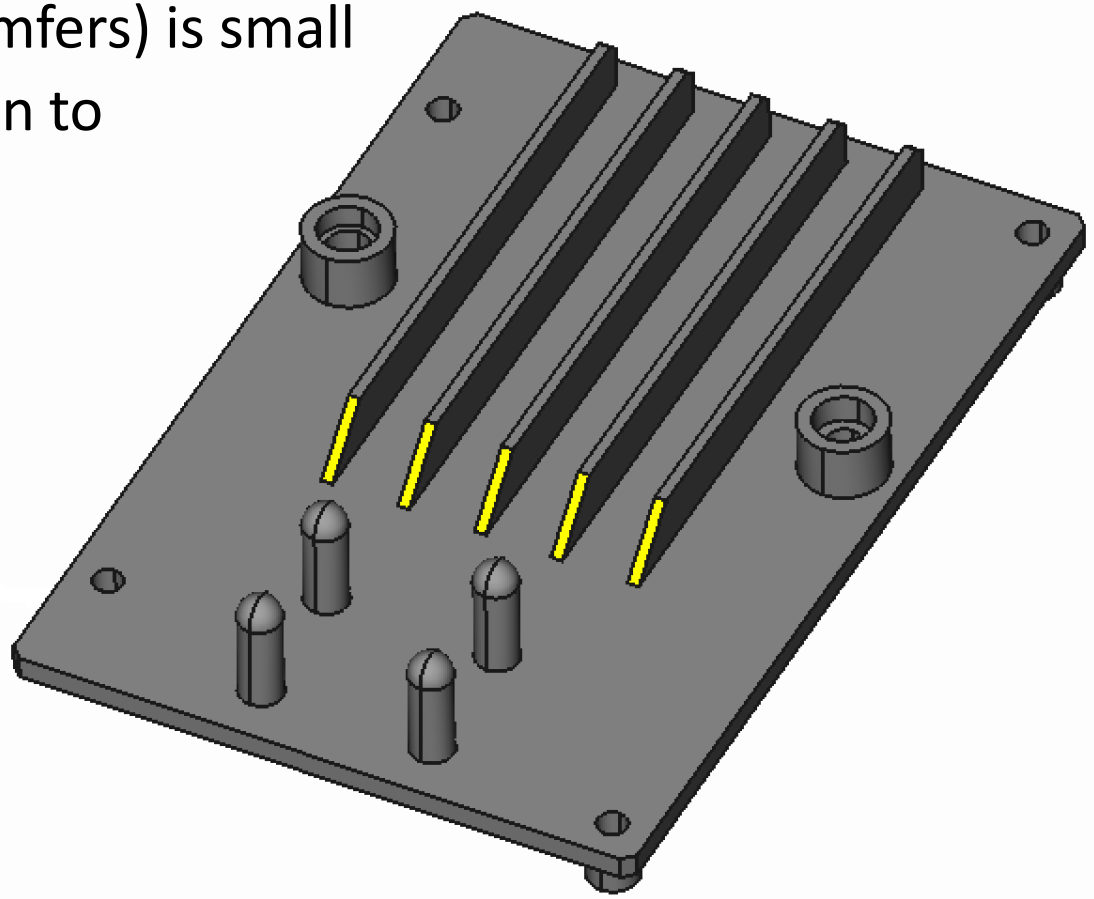
Build Knowledge

- **Cause:** 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
- **Correlation:** Design, Planning, and Program defects



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Execute Solutions

- **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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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

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Install virtual machine

Installation files are included on the USB thumb drives

How to collect manufacturing data from machines?

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*

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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Challenge: Connectivity and Integration

What do you want?

なんでしょう?

was willst du?

Bespoke
Expensive
Lots of expertise

App A

App B

App C

Challenge: Connectivity and Integration

What do you want?

なんでしょう?

was willst du?

Cost
Maintenance
Vendor Lock

Platforms

What info can I provide?

Data
Interoperability
Standards

App
A

App
B

App
C

MTConnect: Mfg Interoperability Standard

- Provides a ***domain model*** for ***manufacturing equipment***
- Enables the creation of ***structured, contextualized data***
- Uses no proprietary format (***open and free!***)
- Designed to be ***read only*** and ***extensible***
- ***Integrates*** with other standards
  - HTTP, XML, …
  - OPC UA, …
  - QIF, B2MML, …

MTConnect®

W. Sobel (2015) *MTConnect Architecture and Research Overview*. Presentation, NAMRC/MSEC2015, June 9, 2015.

MTConnect®

Communications Protocols

Vocabulary and Semantics of the Information Models

Meaningful data yields meaningful results

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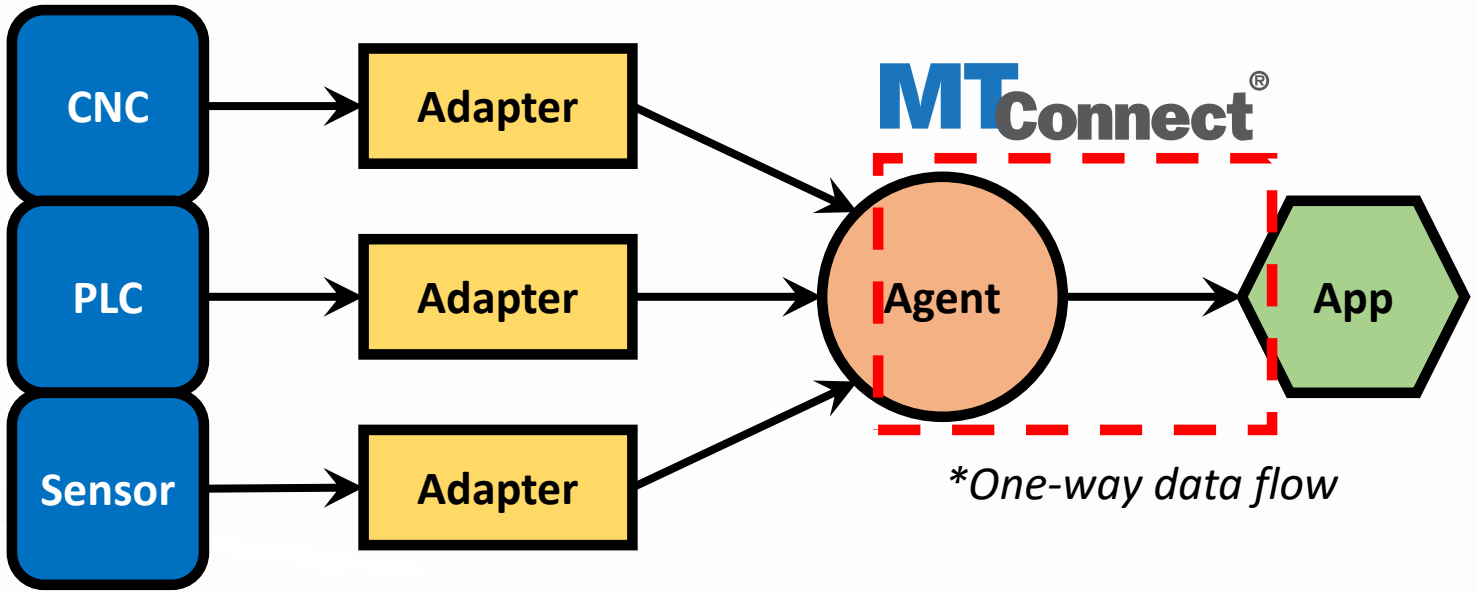
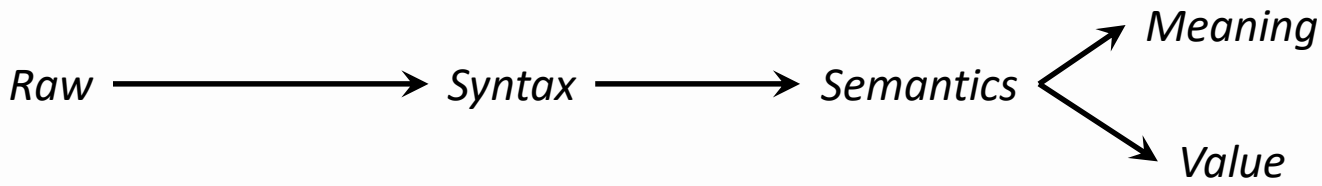
MTConnect: Architecture





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MTConnect: Adapters and Agents

- Optional software and/or hardware stored in:
  - CNC
  - PLC
  - Network
- Responsibilities:
  - Collects (and filters) data from device about current state
  - Publishes data to Agent
- Primarily for legacy systems

- Special purpose HTTP server that provides RESTful interface
- Responsibilities:
  - Organizes and manages data from Adapters
  - Creates and publishes MTConnect response documents based on requests from applications
- Can support one or more devices

W. Sobel (2015) *MTConnect Architecture and Research Overview*. Presentation, NAMRC/MSEC2015, June 9, 2015.

MTConnect: Response Documents

- MTConnectDevices **Infrequent changes**
  - Contains metadata (meaning and structure) about the device
  - Provides logical device structure
  - Has no values!
- MTConnectStreams **Very frequent changes**
  - Contains time series values
  - Uses flattened hierarchy to reduce overhead
  - Reports consistent units and timestamps
- MTConnectAssets **Fairly frequent changes**
  - Contains key/value store for components not integral to device
- MTConnectError

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MTConnect: Data Item Categories

- Events
  - Represent state of specific data item or discrete message or count
- Samples
  - Represent continuous variables sampled at a given rate
- Conditions
  - Represent health of a specific component

Agent only reports deltas
Availability (Event) is the only required data item

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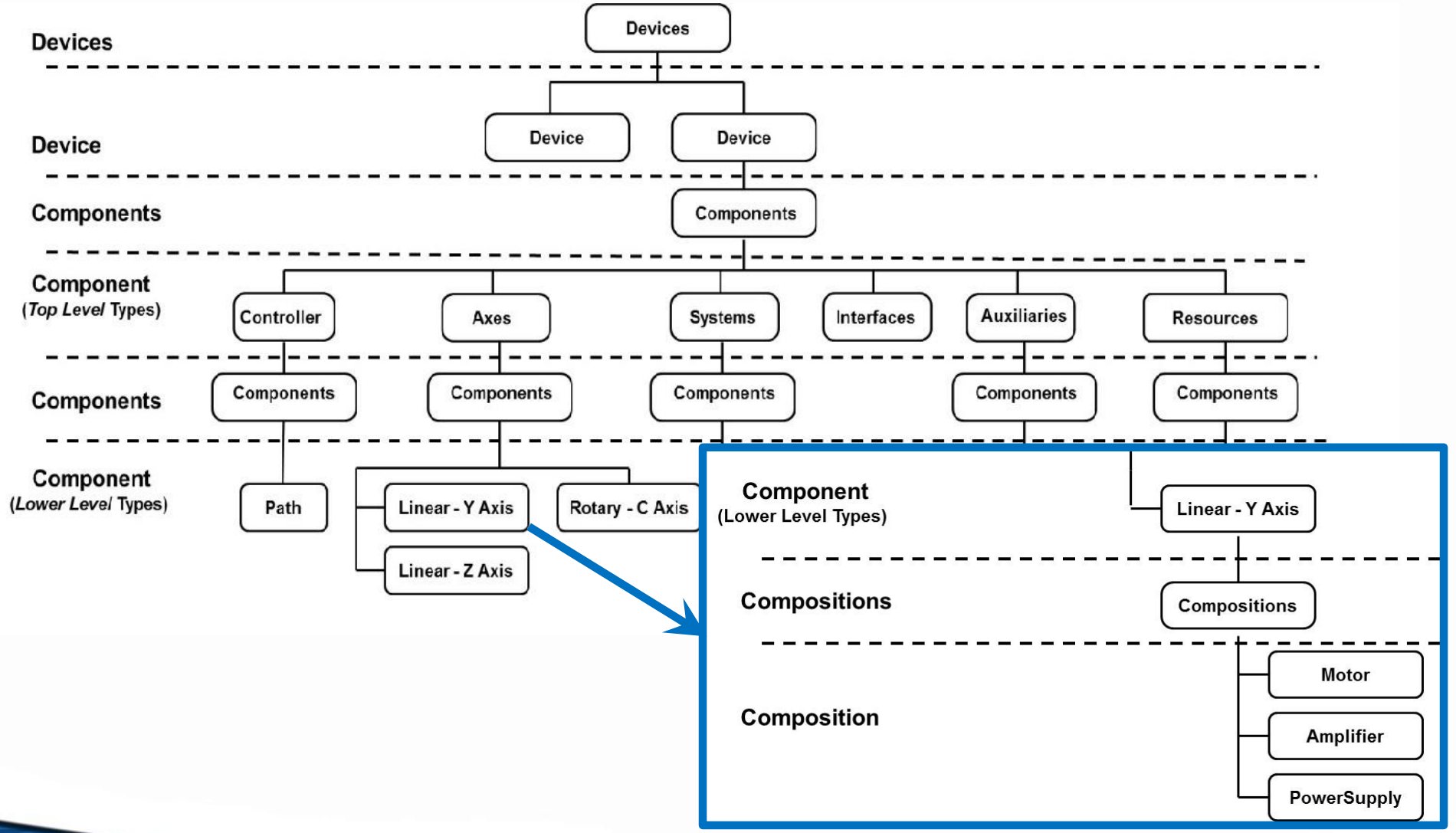
MTConnect: Data Hierarchy



MTConnect: Request Protocol

- probe
  - Returns MTConnectDevices
- current
  - Returns MTConnectStreams at a point in time
- sample
  - Returns MTConnectStreams for a given number of entries
- asset
  - Returns MTConnectAssets

XPATH can be used to filter data: Append 'path=<xpath>' to URL

More examples to follow!

https://smstestbed.nist.gov/vds/[request]
https://smstestbed.nist.gov/vds/[device]/[request]

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MTConnect: Implementation and Configuration

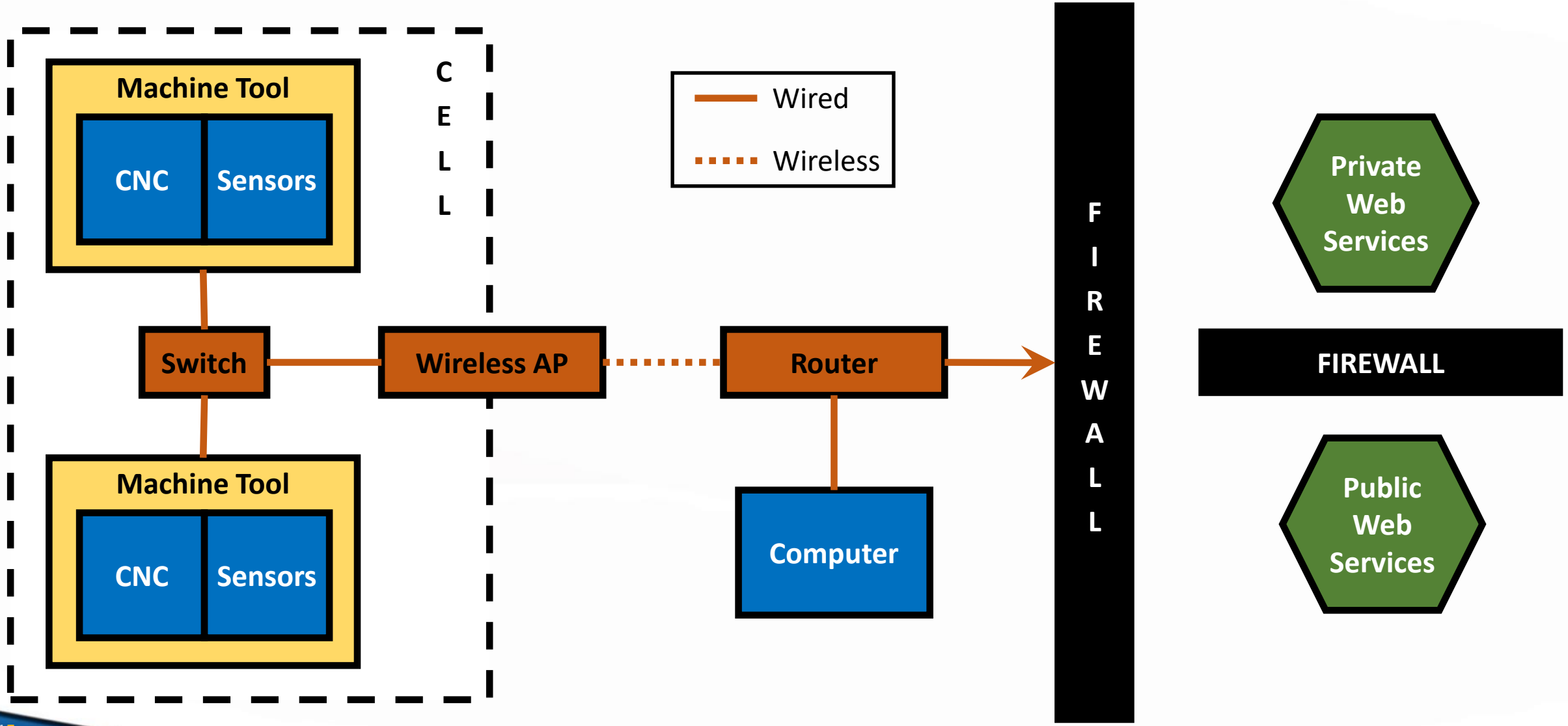
- Build Agent for device(s)
  - Open-source reference agent (or create your own)
  - Model device (devices.xml)
  - Configure Agent (agent.cfg): locate adapters, schemas; set buffer size
- Run Agent
- Remember:
  - Not every device provides the same data items
  - Not every device may be modeled identically
  - Not every device may offer data at equivalent or consistent rates

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.

Example of Physical Implementation



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

BREAK

10 minutes

Collecting manufacturing data

Interactive Exercise

Curating manufacturing data

Interactive Exercise

BREAK

10 minutes

Querying manufacturing data

Interactive Exercise

Workshop close-out

Question & Answer

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

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!

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