Using the Digital Thread to Integrate PHM in a Model-Based Enterprise (MBE)

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Presented to the *10th Annual Conference of the Prognostics and Health Management (PHM) Society*

25 September 2018

Ripped from the Headlines…

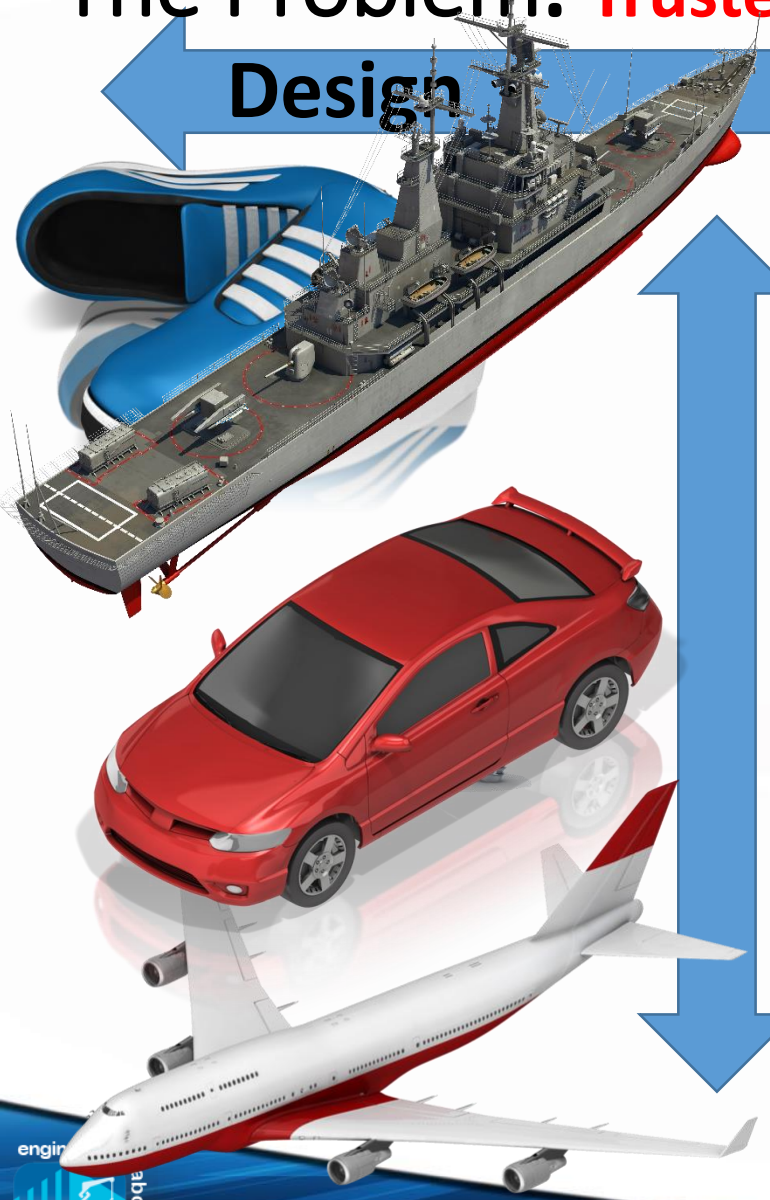
Got Data? Need Decisions?

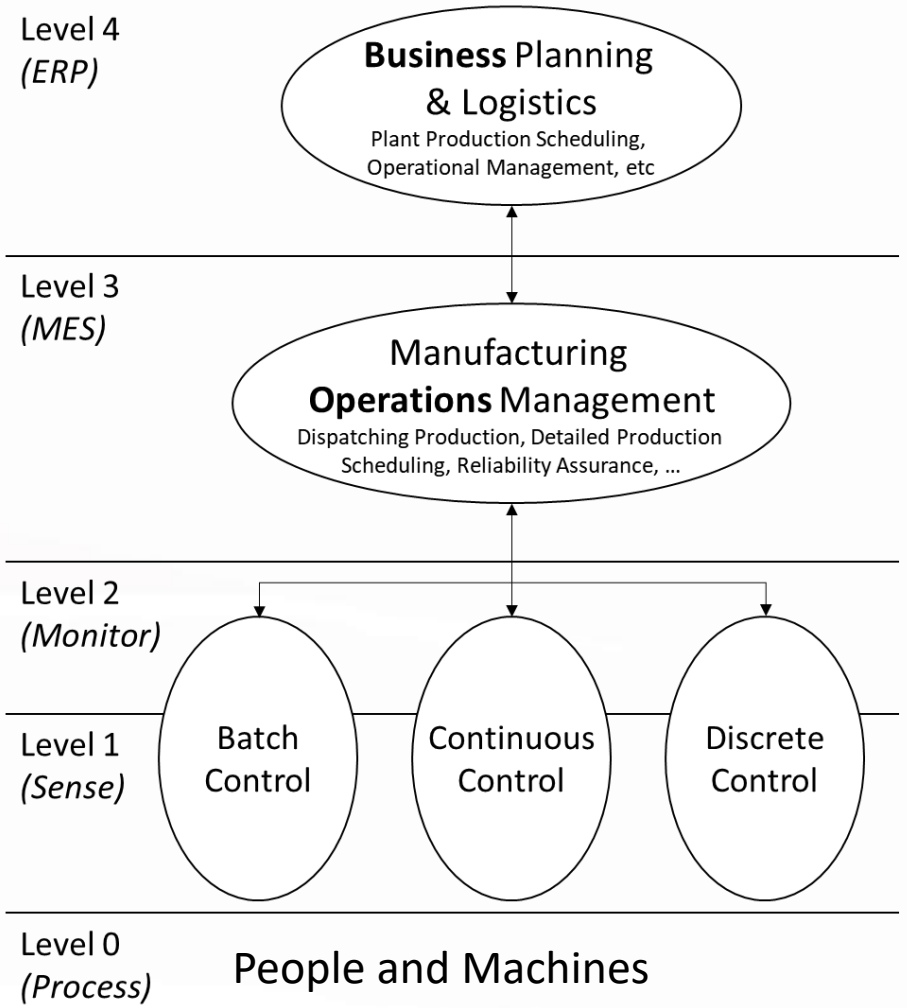
Presentation Overview

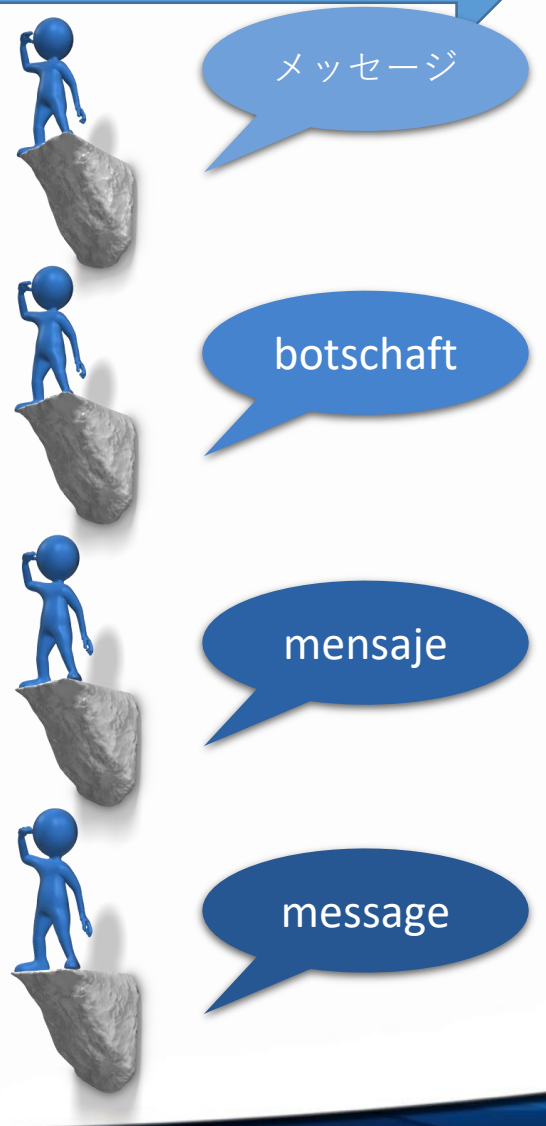
- What's the problem in the context of maintaining manufacturing systems?
- Digital Threads in a Model-Based Enterprise
- A Prototype of the Connections

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 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

- MRO/Sustainment needs distributed manufacturing to figure out what capabilities & capacities are located where and what is the topology of that distributed network

- Simplicity through distributed complexity [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…

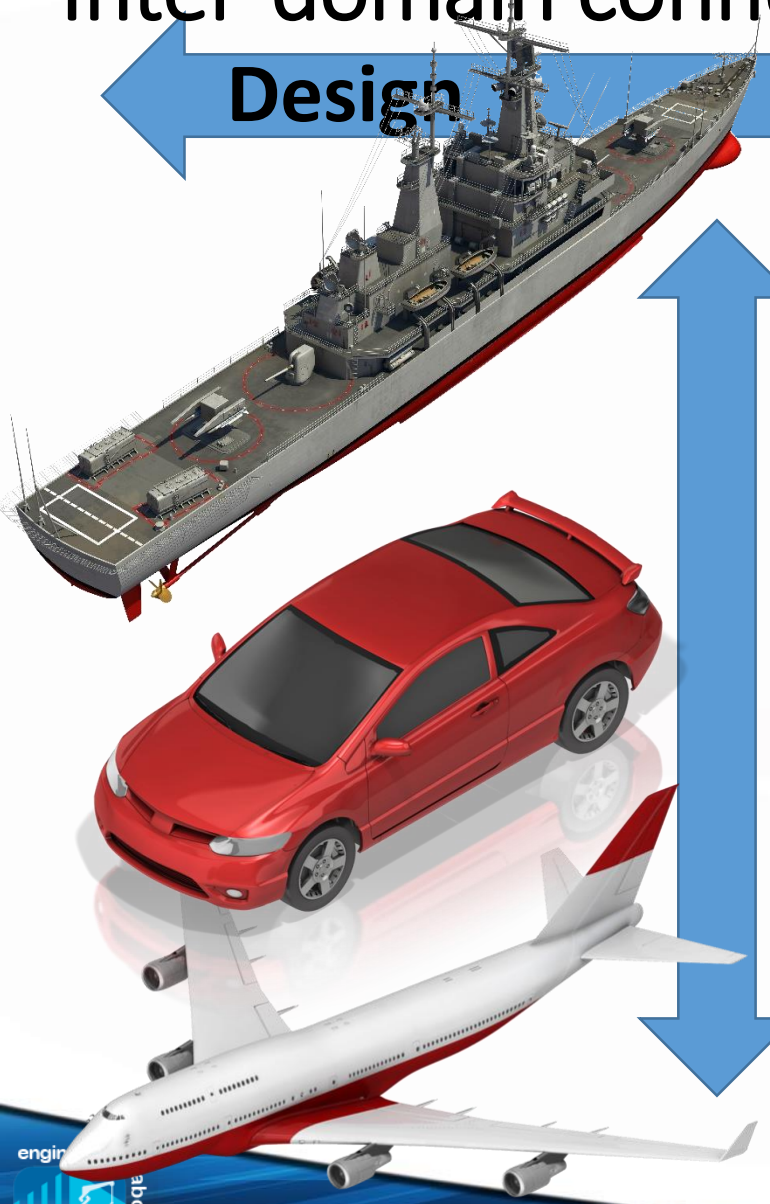
- The National Security Strategy includes producing parts and systems with healthy and secure supply chains supported by a skilled U.S. workforce as essential to the Nation’s manufacturing readiness

- 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

Inter-domain connections

Design **Manufacturing** **Sustainment**



Level 4 *(ERP)*

Business Planning & Logistics
Plant Production Scheduling, Operational Management, etc

Level 3 *(MES)*

Manufacturing **Operations** Management
Dispatching Production, Detailed Production Scheduling, Reliability Assurance, …

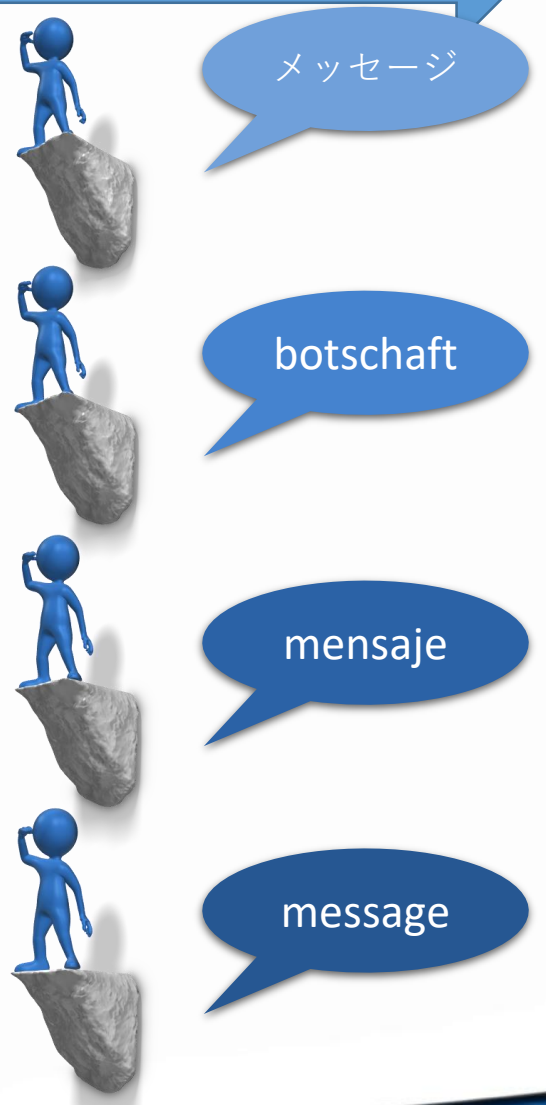
Level 2 *(Monitor)*

Level 1 *(Sense)*

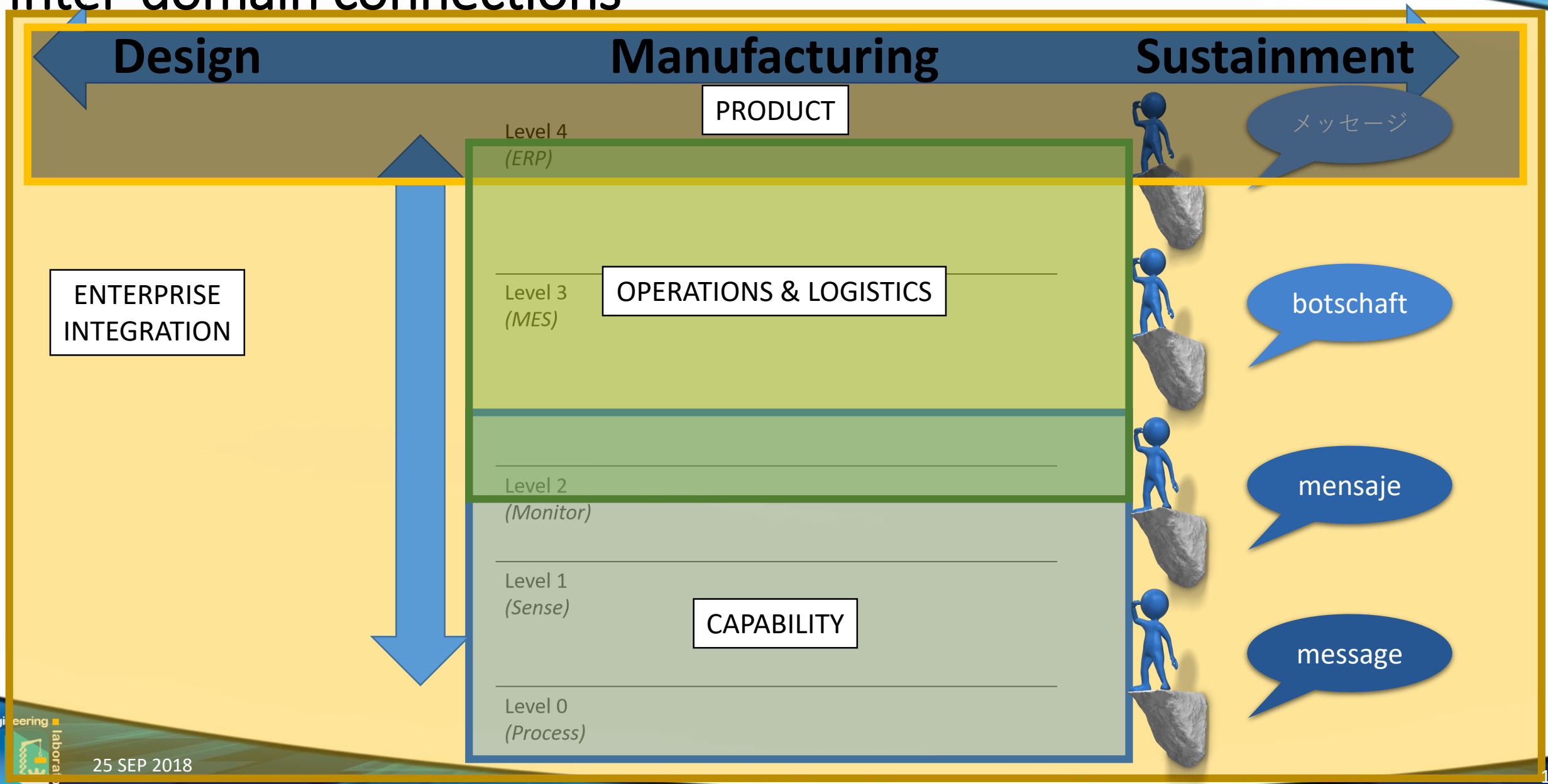
Batch Control | Continuous Control | Discrete Control

Level 0 *(Process)*

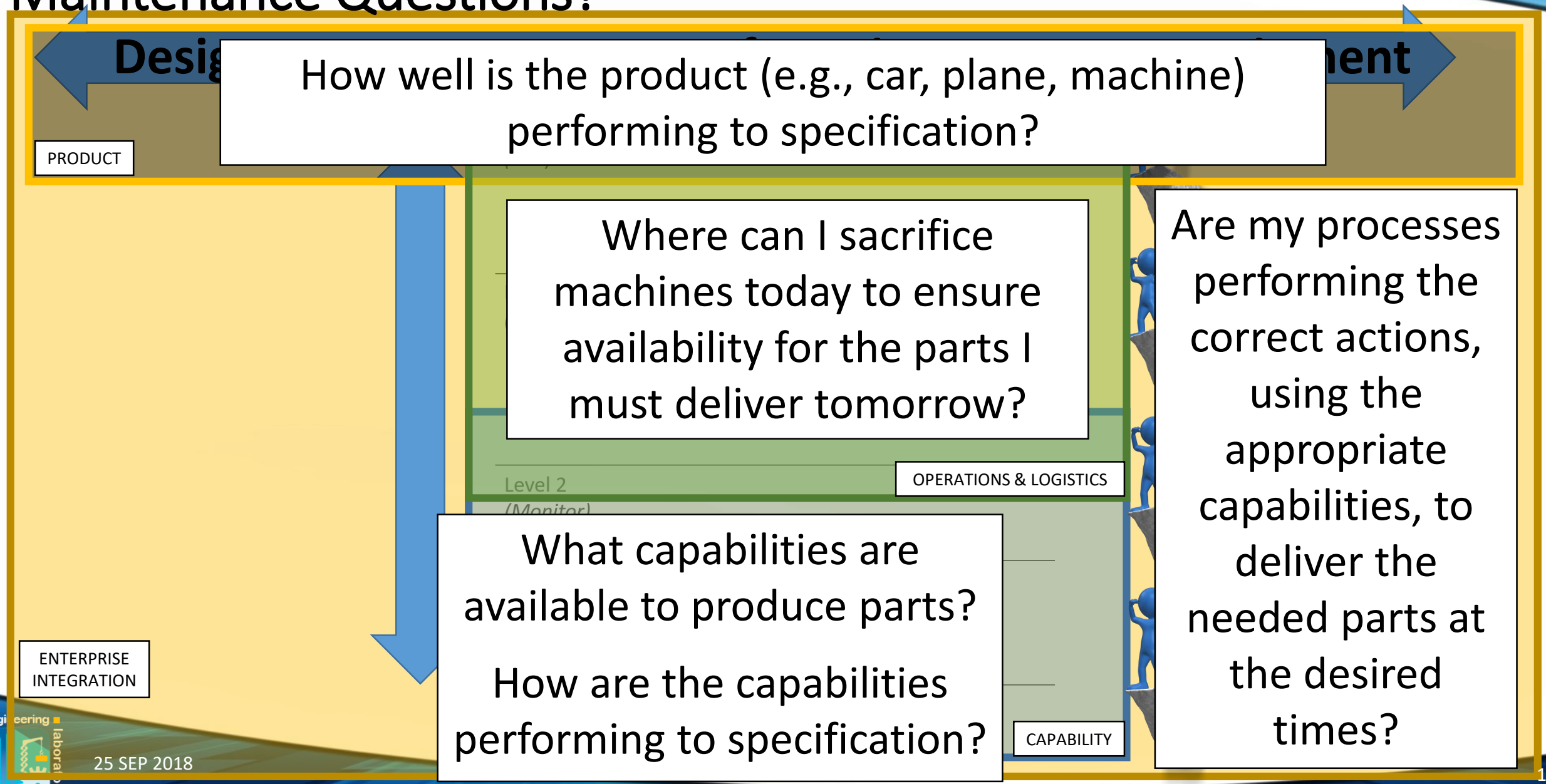
People and Machines



Inter-domain connections



Maintenance Questions?



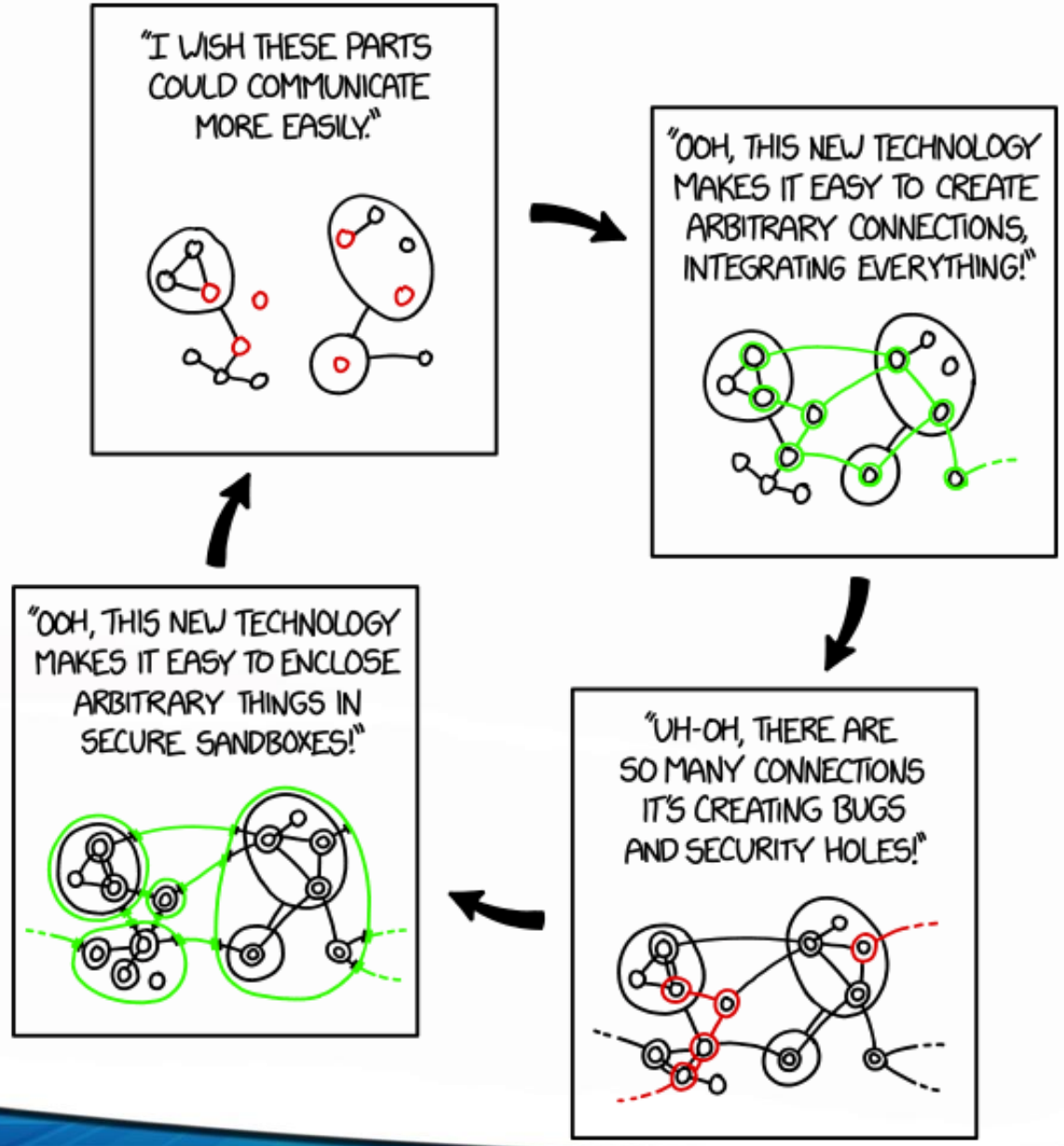
Digital Threads in a Model-Based Enterprise

Paradigm Shifts: Diagnosis to Prognosis

- Changes in Operations and Logistics
  - Spare parts providers and logistics partners must deliver when needed
  - Requires IT / OT integration between OEM, Suppliers, and Field Servicers
  - Must be able to mitigate impulse functions
- Viewpoints Interoperability
  - Context varies based on the phase of the lifecycle (e.g., design, manufacturing, quality)
  - Context varies based on the level of interaction with data (e.g., systems, operations, enterprises)
  - Data → Domain Interoperability via “Standard Interfaces”

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/

Enter Digital Thread and Digital Twins

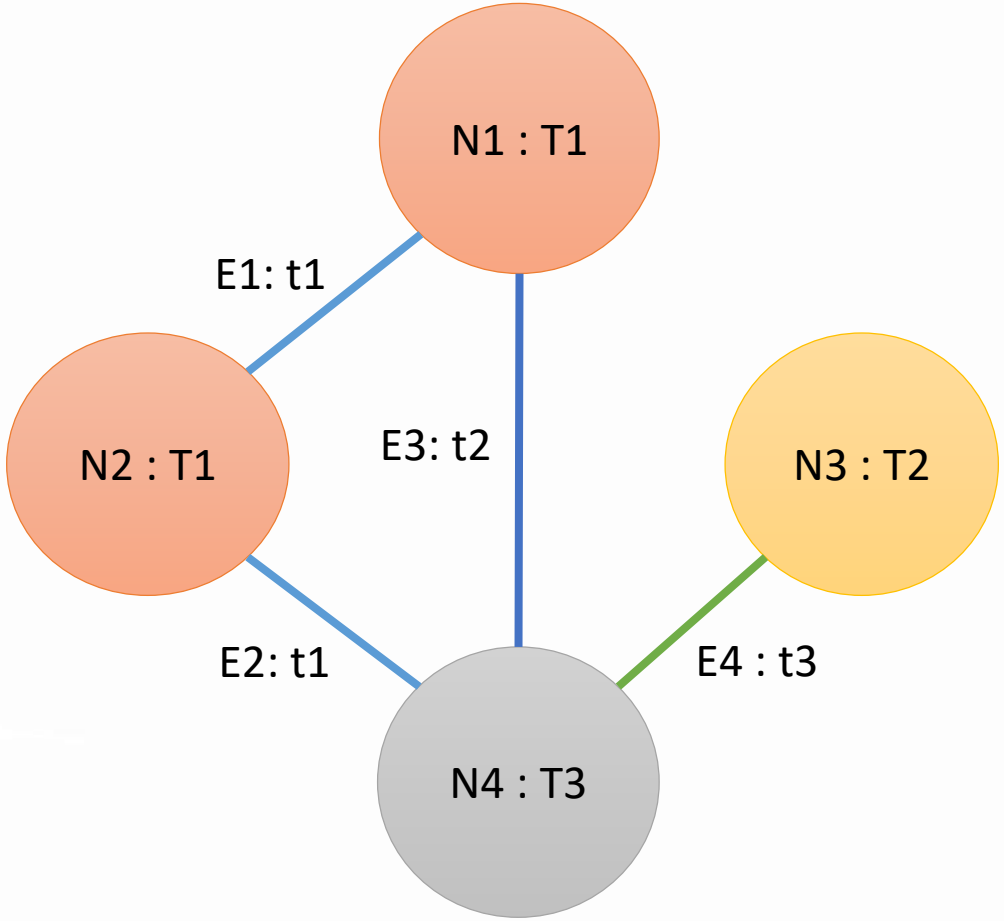
Surrogates

- Digital Thread, *noun*
  - A connected information flow between standard interfaces for activities across the product lifecycle

- Digital Surrogate, *noun*
  - An application of the digital thread to an environment where integrated information flows are leveraged to digitize systems and apply modeling and simulation to enable dynamic control

Digital Thread is a Graph

- Graph – Nodes and Edges
- Nodes and Edges may have
  - Name
  - Type (Typed Graph)
  - Properties (Property Graph)
- Edges may have
  - Direction (Directed vs. Undirected Graph)
- Graphs can be
  - Stored
  - Queried (Pattern matching)
  - Traversed (e.g. Breadth-first, Depth-first)
  - Generated and Transformed
  - Analyzed



Bajaj, M., & Hedberg, T. (2018). System Lifecycle Handler - Spinning a Digital Thread for Manufacturing. *INCOSE International Symposium*, *28*(1), 1636–1650. DOI: 10.1002/j.2334-5837.2018.00573.x

Deploying Digital Thread

- Use consensus-based, voluntary, open standards to:
  - Validate
  - Certify
  - Connect

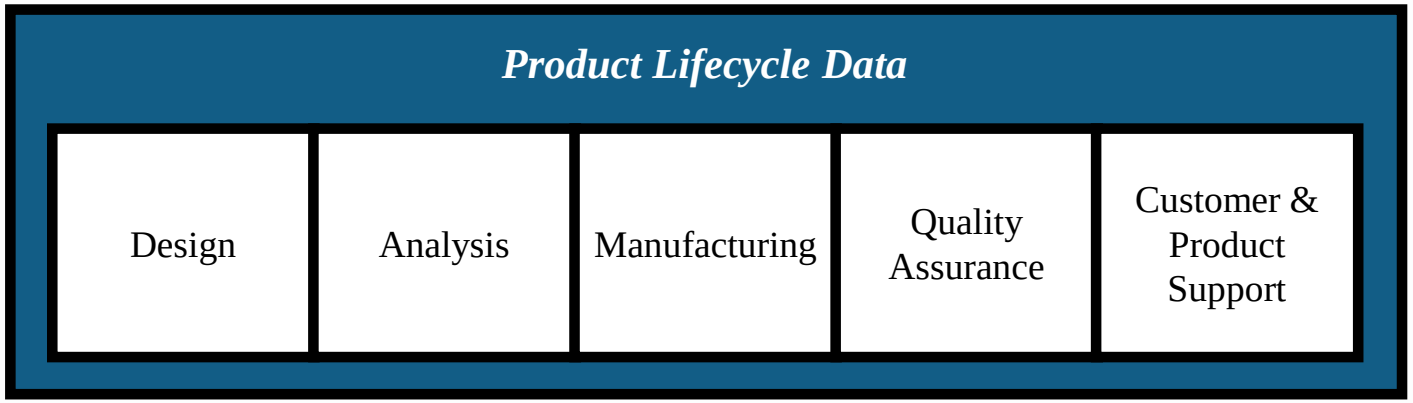
- Goals
  - Seamless traceability:
    System -> Design -> Manufacturing -> Operations -> Maintenance
  - High-quality, 100% first-pass process yields
  - Enterprise knowledge re-use

Lifecycle Information Framework and Technology

FROM INFORMATION SILOS…

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

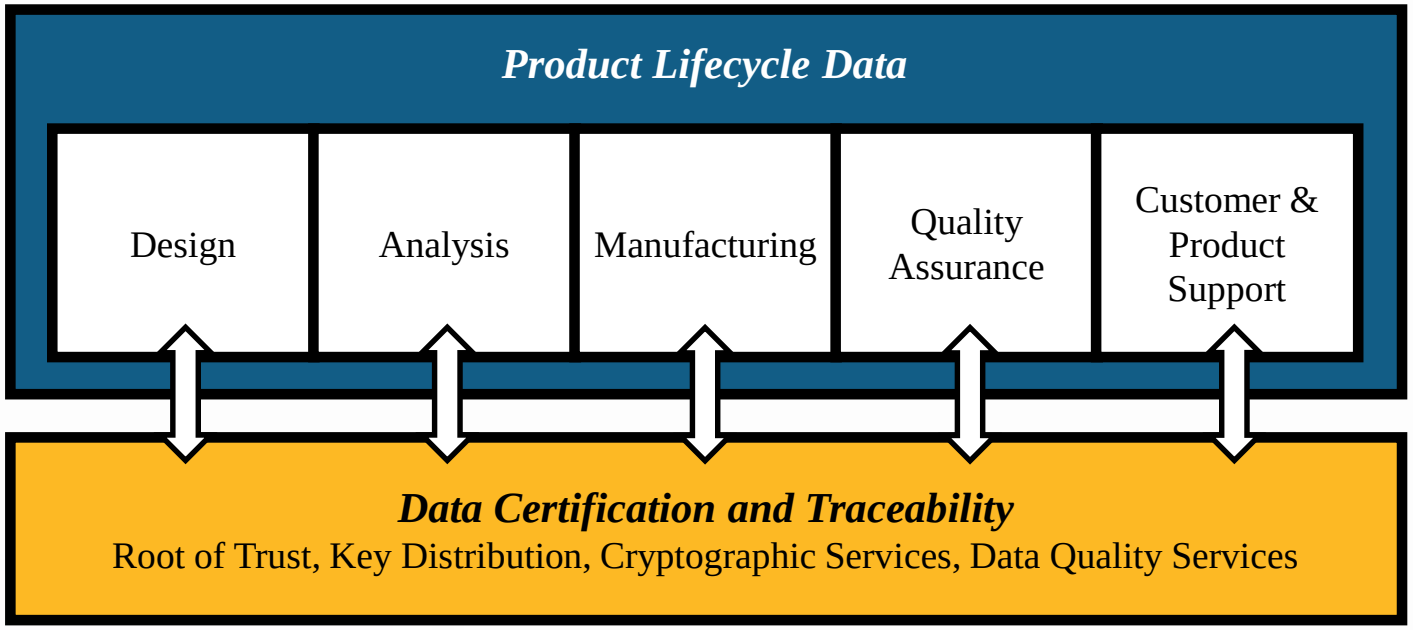
Lifecycle Information Framework and Technology



…TO LINKED DATA…

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

Lifecycle Information Framework and Technology

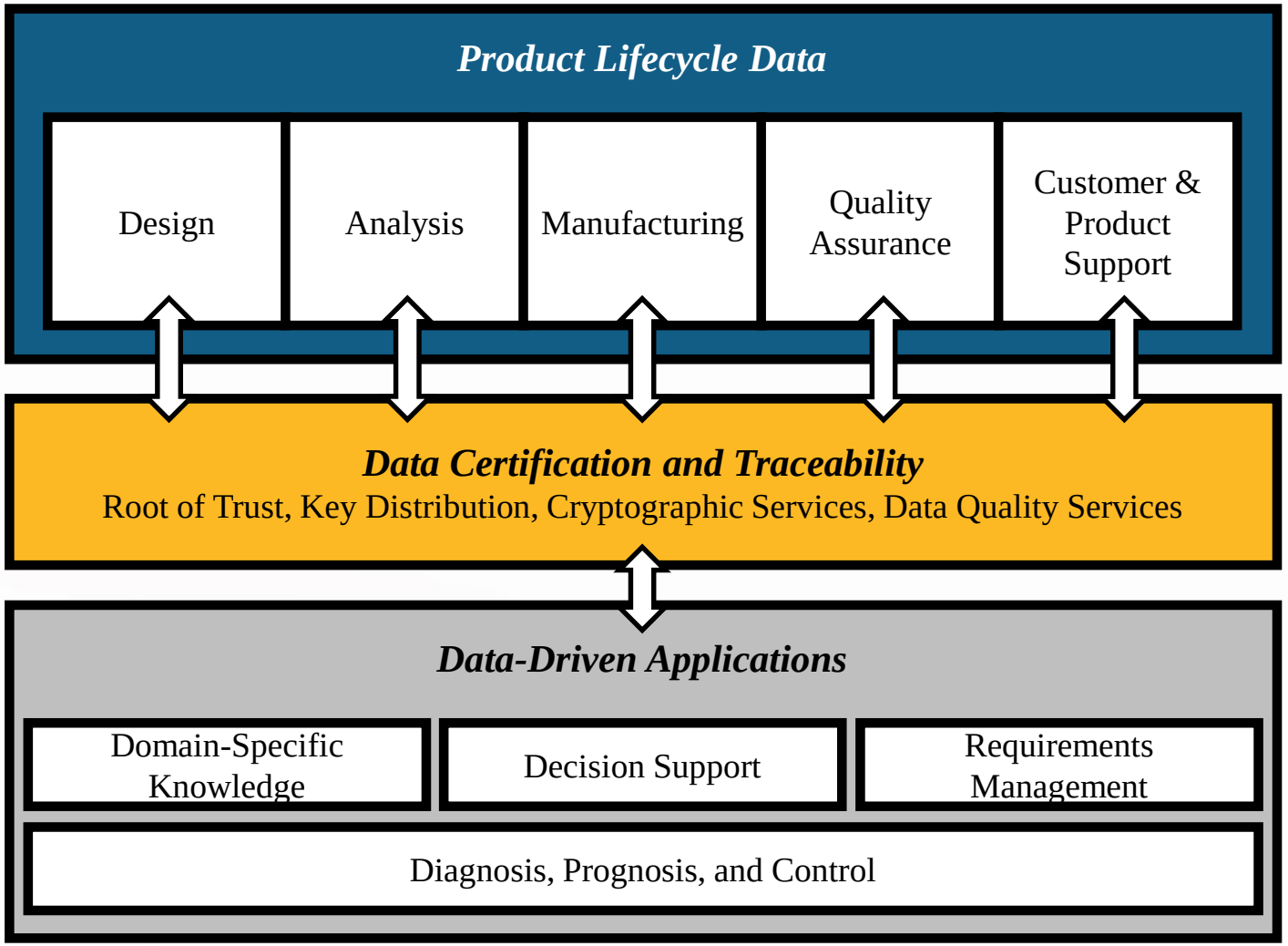


…WITH BUILT IN TRUST AND TRACEABILITY…

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

Lifecycle Information Framework and Technology

…FOR DRIVING APPLICATION WITH DATA!



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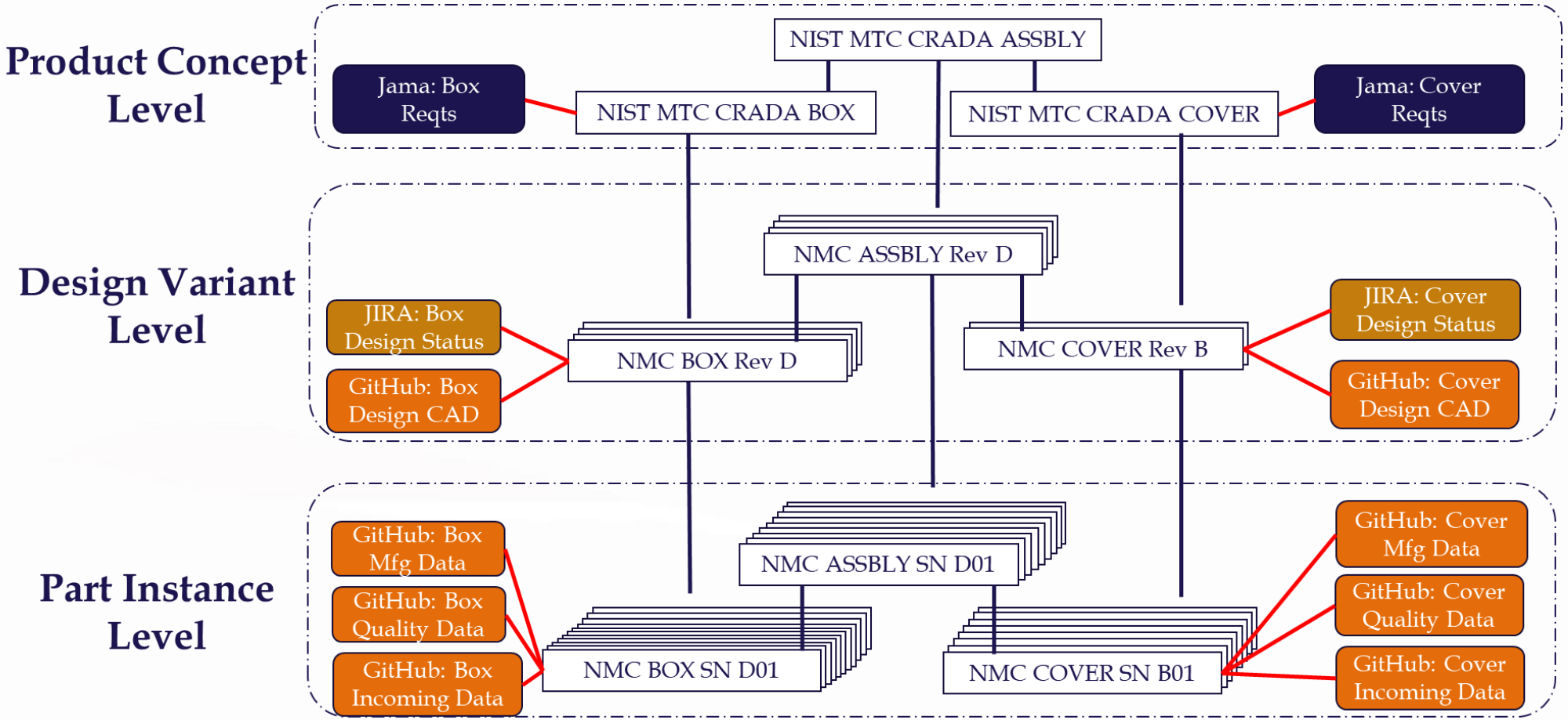
A Prototype of the Connections

Use Case: A three component assembly with design, manufacturing, and inspection data

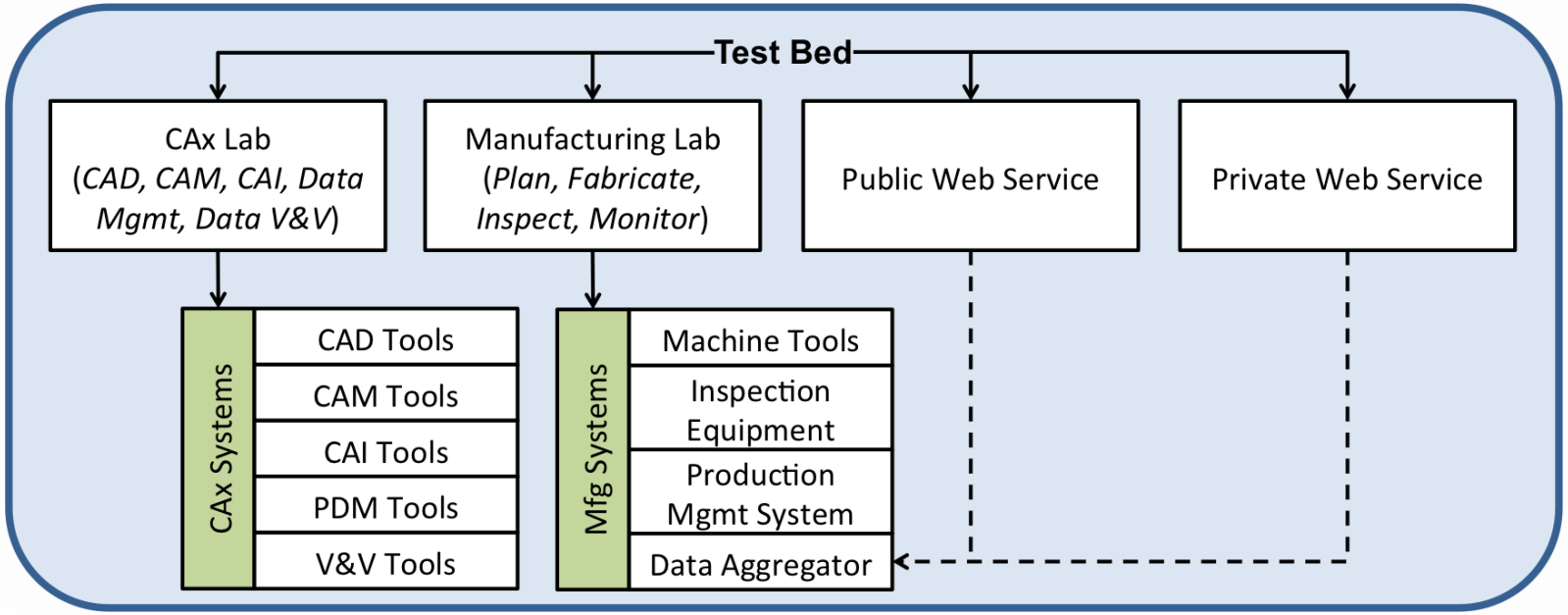


Hedberg Jr., T. D., Sharp, M. E., Maw, T. M., Rahman, M. M., Jadhav, S., Whicker, J. J., … Helu, M. M. (In Press). A three component assembly with design, manufacturing, and inspection data from a collaboration between the National Institute of Standards and Technology and the Manufacturing Technology Centre. *NIST Journal of Research (NIST JRES), 1-2.*

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

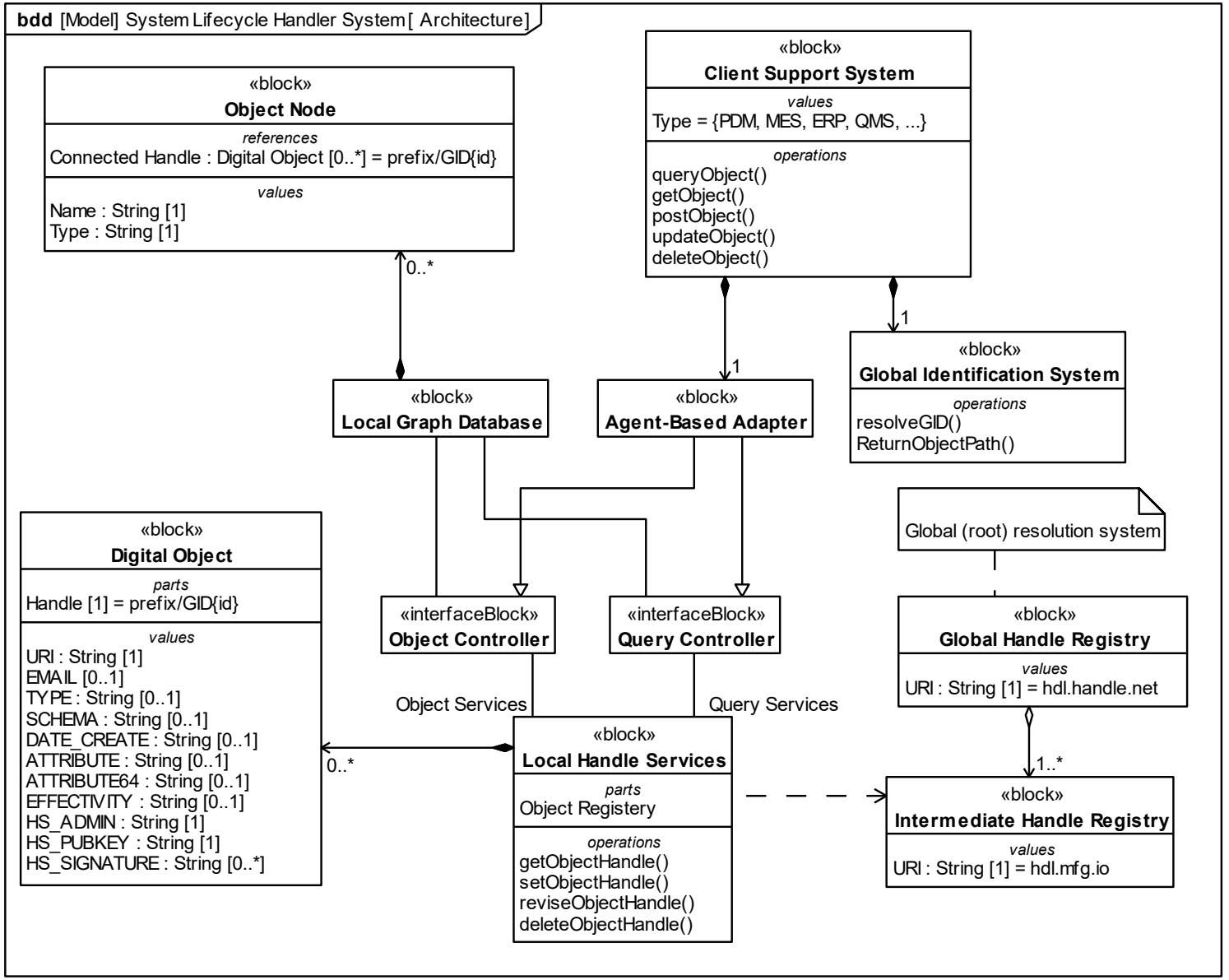


M. Helu, T. Hedberg (2015) Enabling Smart Manufacturing Research and Development using a Product Lifecycle Test Bed. *Procedia Manufacturing*, 1, 86-97. DOI:10.1016/j.promfg.2015.09.066.

Generating Connections

Generated Connections between cyber and physical things for assembly and two components

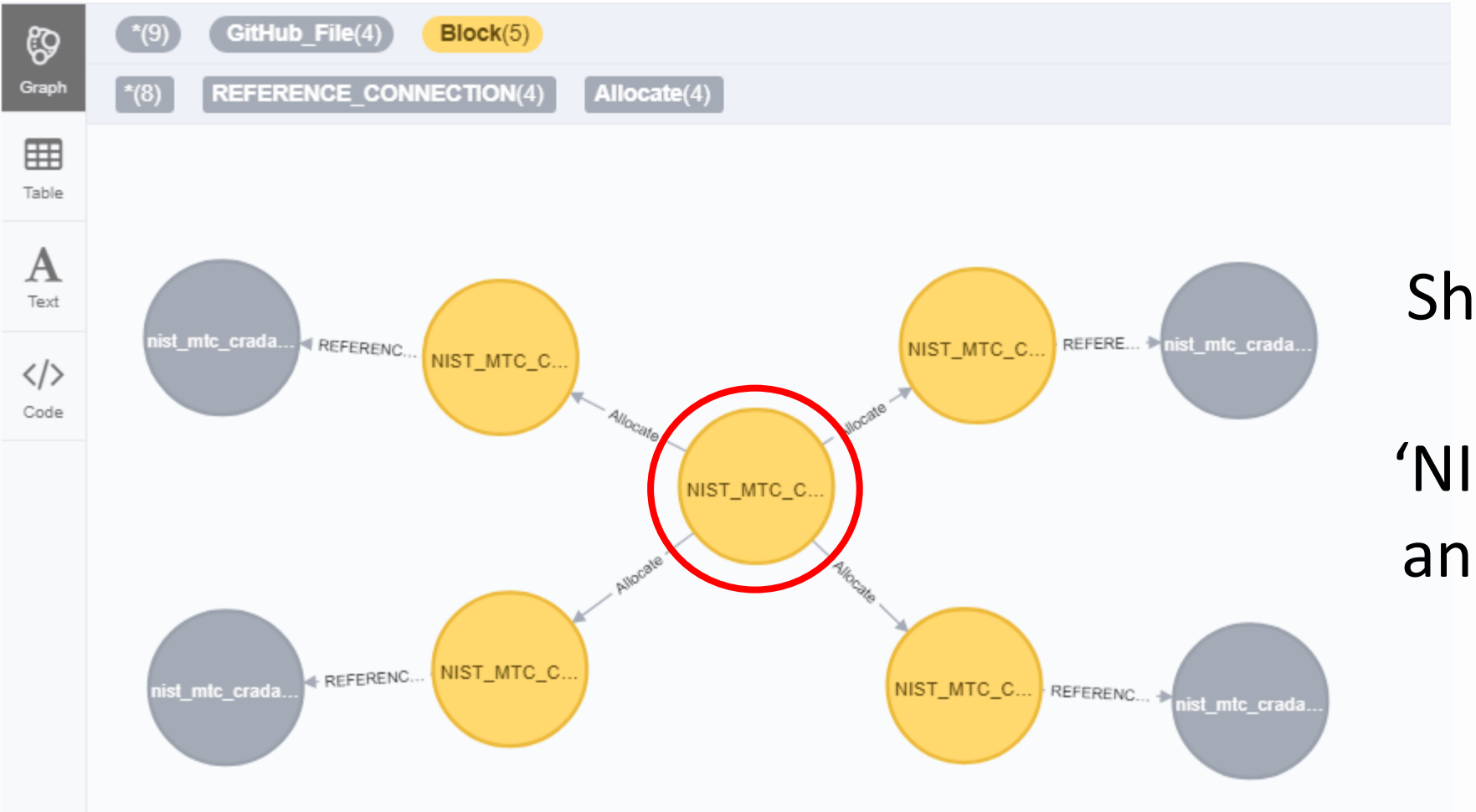
- 145 nodes
- 436 edges



Hedberg Jr, T., Bajaj, M., & Camelio, J. A. (In Review). Using graphs to link data across the product lifecycle for enabling smart manufacturing digital threads. *Journal of Computing and Information Science in Engineering.*

Graph Database Queries

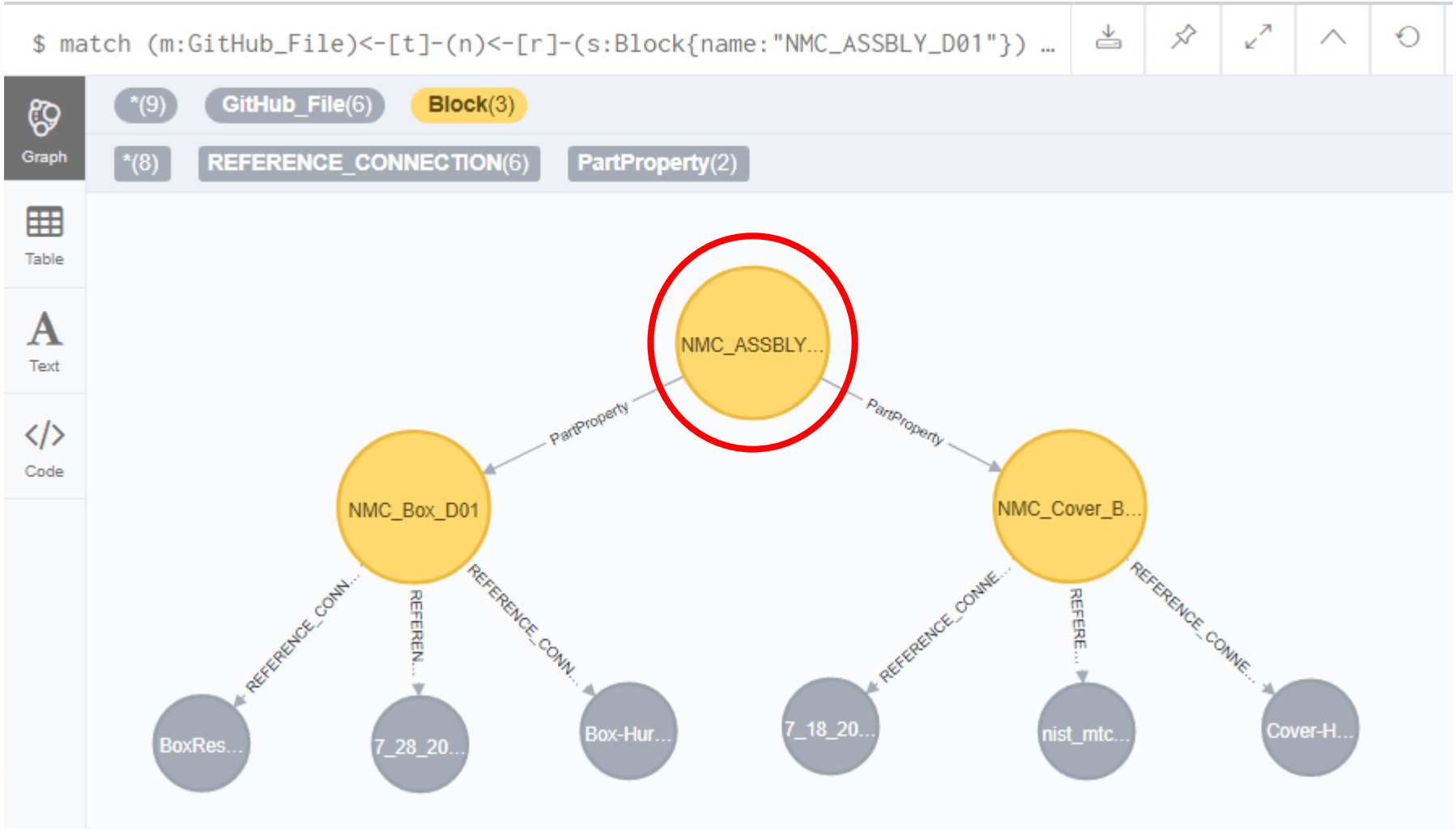
```
$ match (m:GitHub_File)-[t]-(n:Block)-[r]-(s:Block{name:"NIST_MTC_CRADA_BOX"}) RETURN m,t,n,r,s
```



Show all Design Variants of Product Concept 'NIST_MTC_ CRADA_Box' and associated CAD data

Bajaj, M., & Hedberg, T. (2018). System Lifecycle Handler - Spinning a Digital Thread for Manufacturing. *INCOSE International Symposium*, *28*(1), 1636–1650. DOI: 10.1002/j.2334-5837.2018.00573.x

Graph Database Queries



Show all Mfg and Quality data associated with Part Instance ‘NMC_ASSBLY_D01’

Bajaj, M., & Hedberg, T. (2018). System Lifecycle Handler - Spinning a Digital Thread for Manufacturing. *INCOSE International Symposium*, *28*(1), 1636–1650. DOI: 10.1002/j.2334-5837.2018.00573.x

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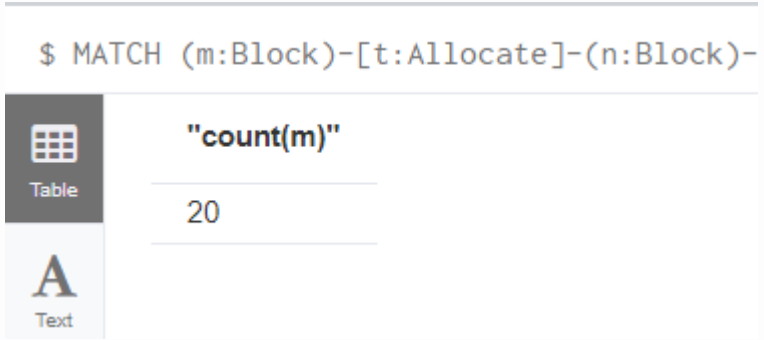
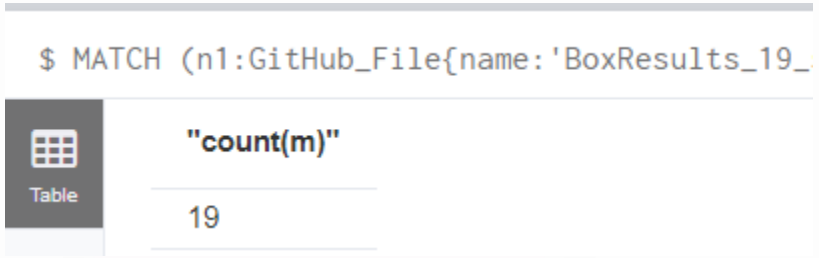
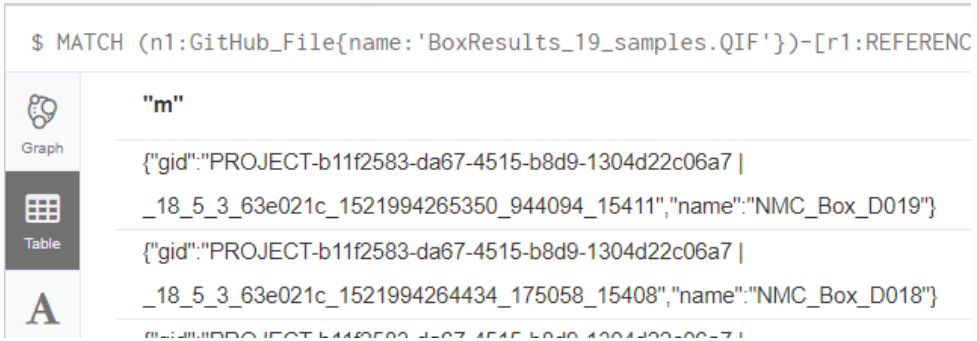






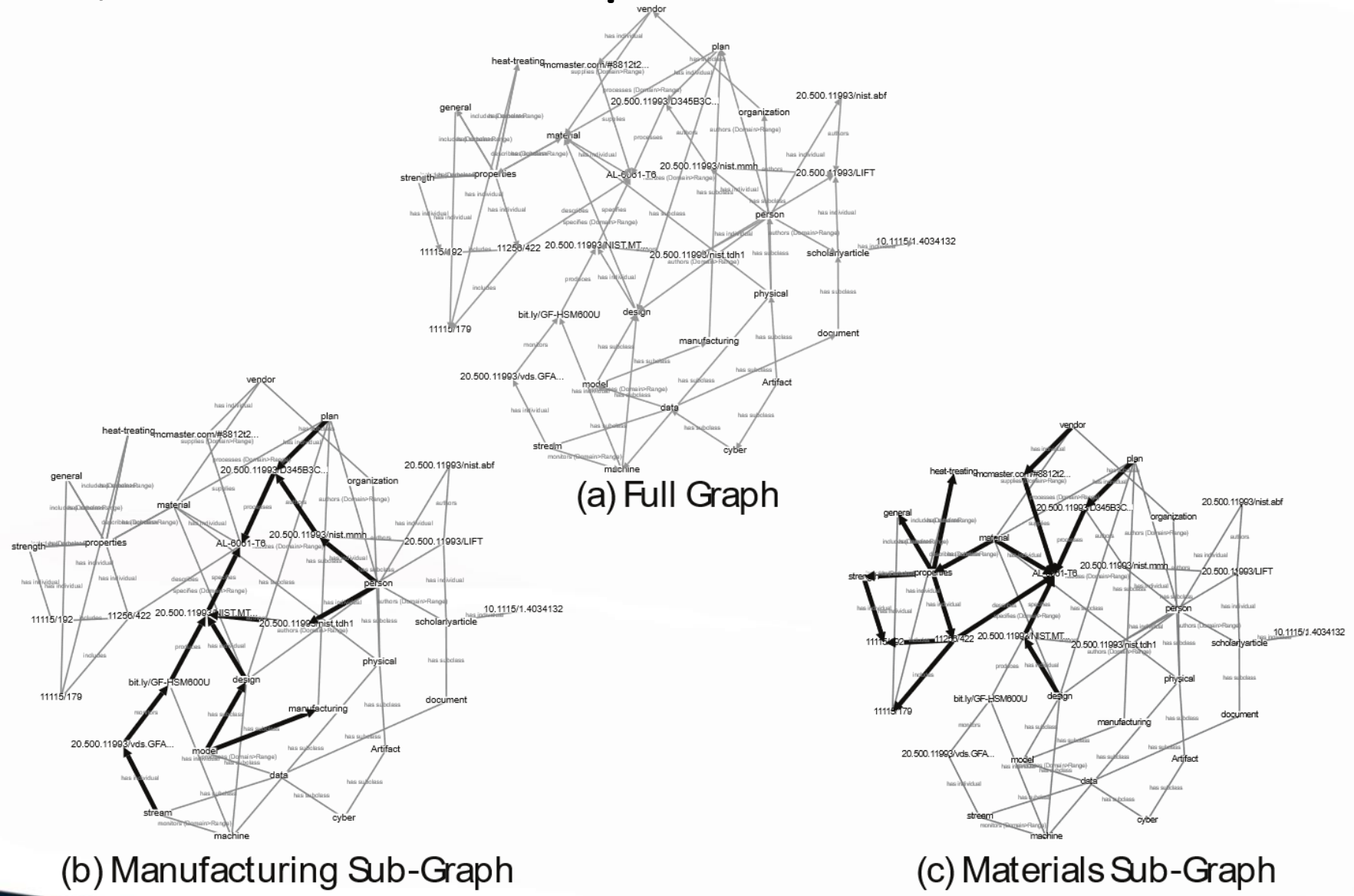
How many instances of Box have been manufactured?

How many instances of Box have been through incoming inspection?

List them

Bajaj, M., & Hedberg, T. (2018). System Lifecycle Handler - Spinning a Digital Thread for Manufacturing. *INCOSE International Symposium*, *28*(1), 1636–1650. DOI: 10.1002/j.2334-5837.2018.00573.x

Dynamic, Contextual Viewpoints



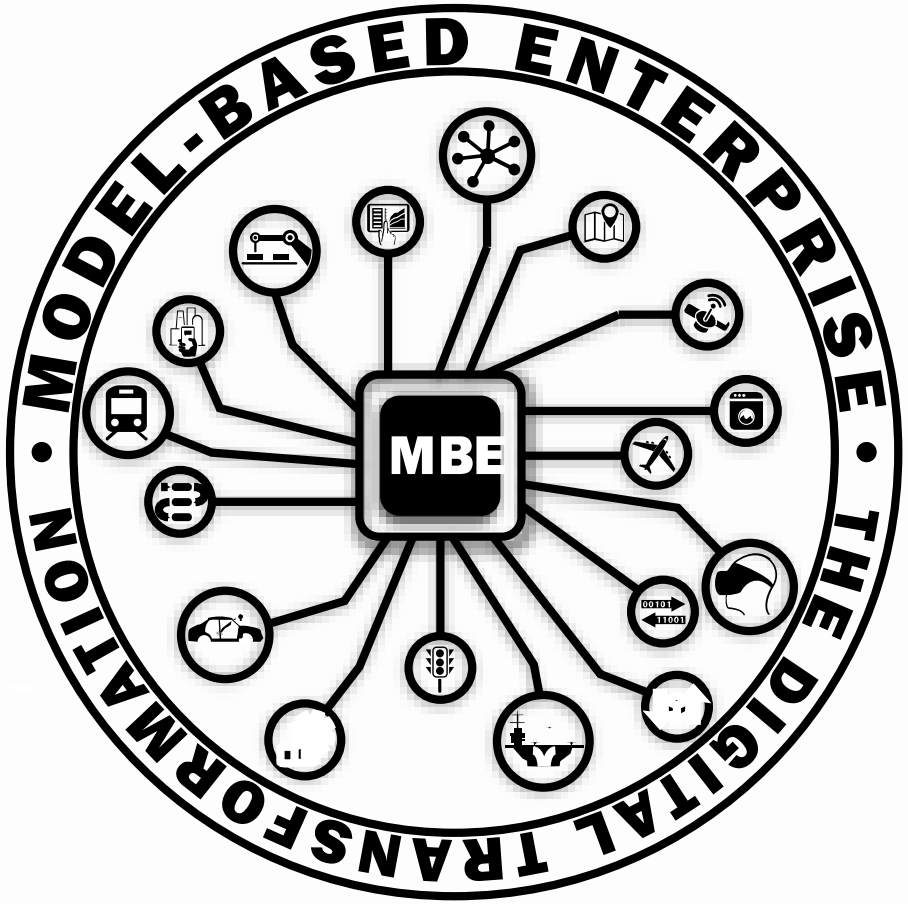
(a) Full Graph

(b) Manufacturing Sub-Graph

(c) Materials Sub-Graph

Summary

- PHM 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 and knowledge extraction
- 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

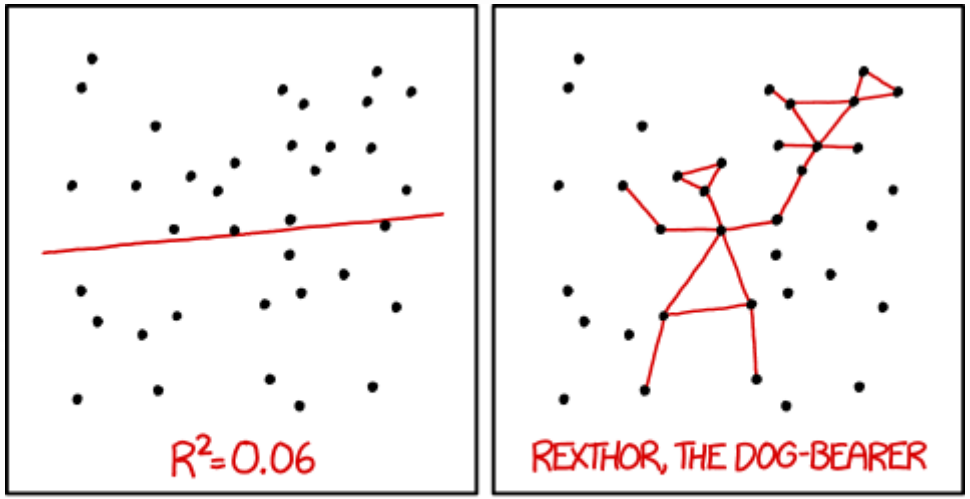
MBE Program: URL to come

Digital Thread: https://go.usa.gov/xNP8x

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/

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