Benefits in MBE

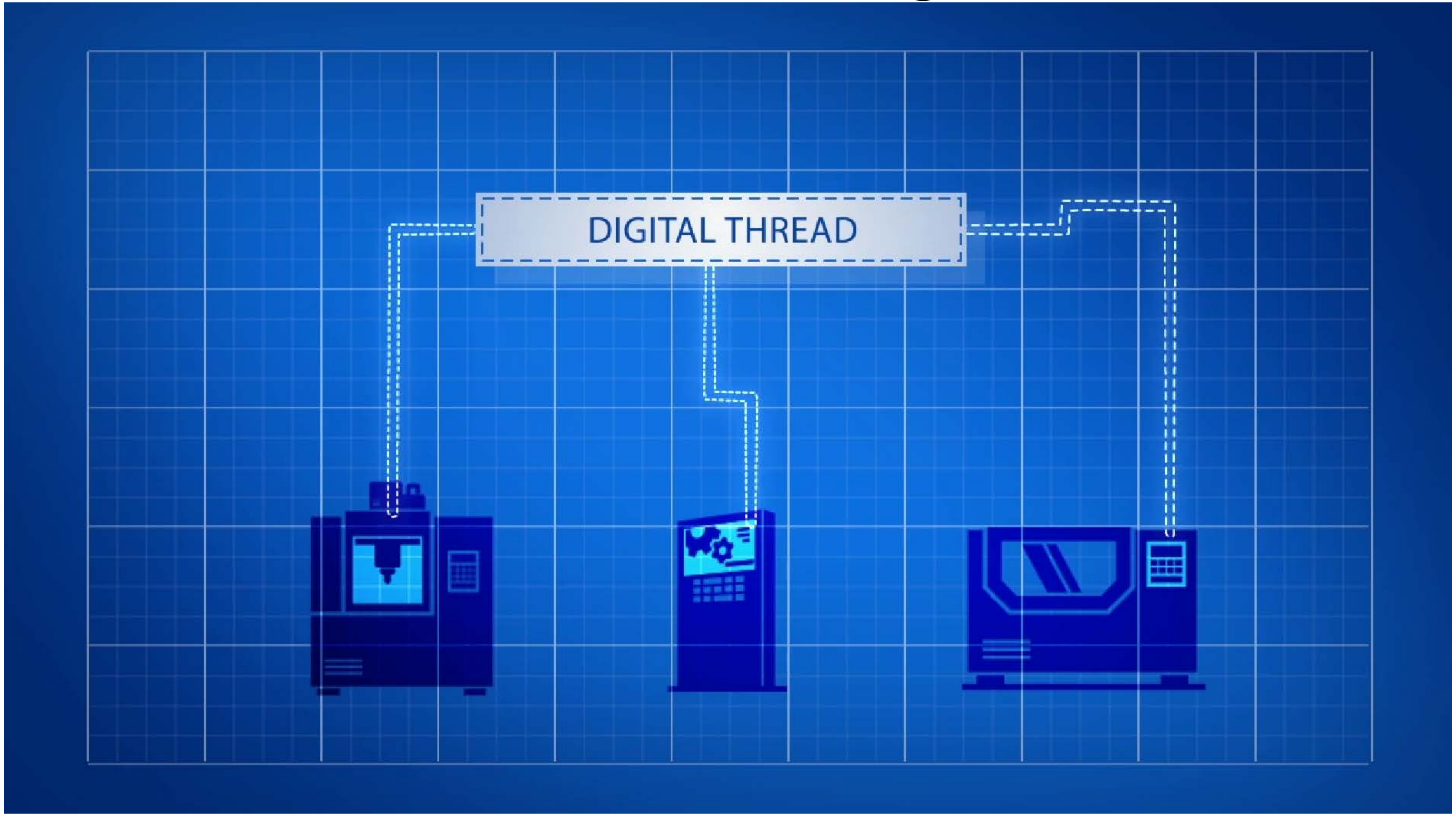
A brief on the *Testing the Digital Thread* and *Design to Manufacturing and Inspection* projects and related projects

MBE Summit 2017

4 April 2017, Gaithersburg MD

MBE 101

Putting the Digital Thread into a Manufacturing Context



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.

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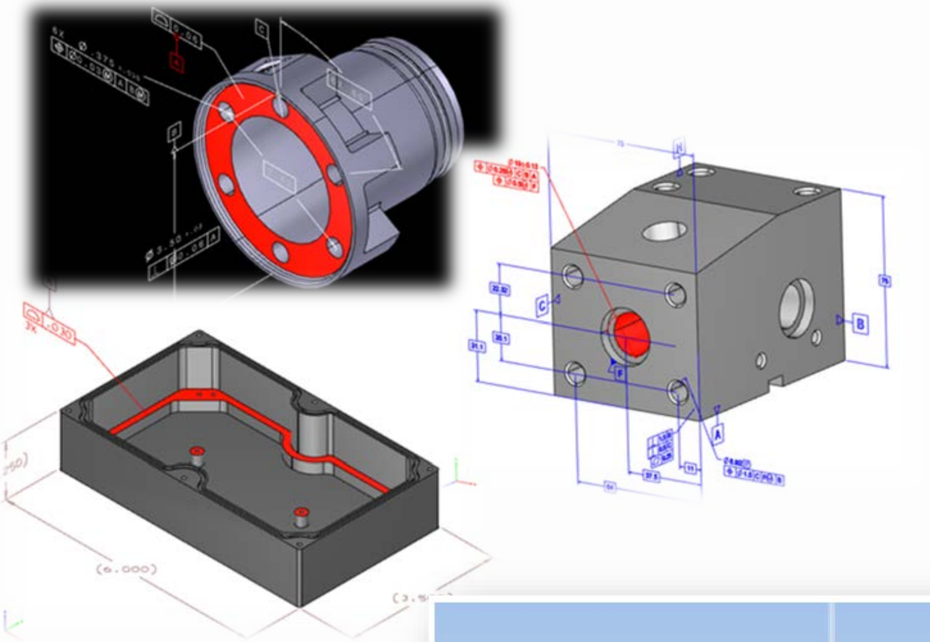
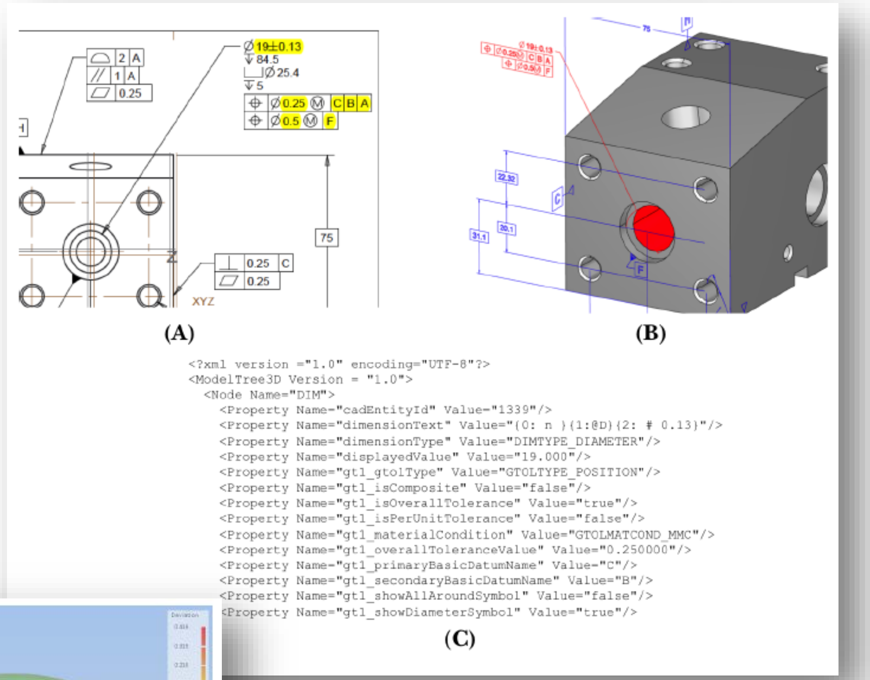
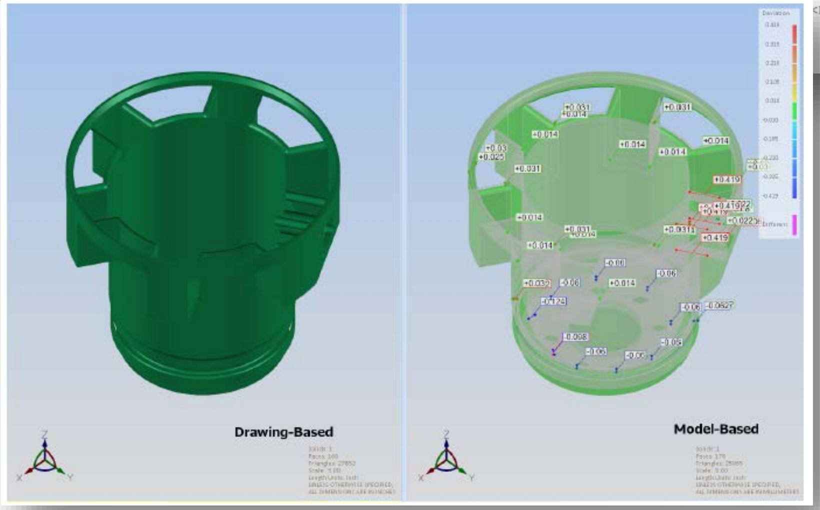
Testing the Digital Thread (TTDT)

The Problem

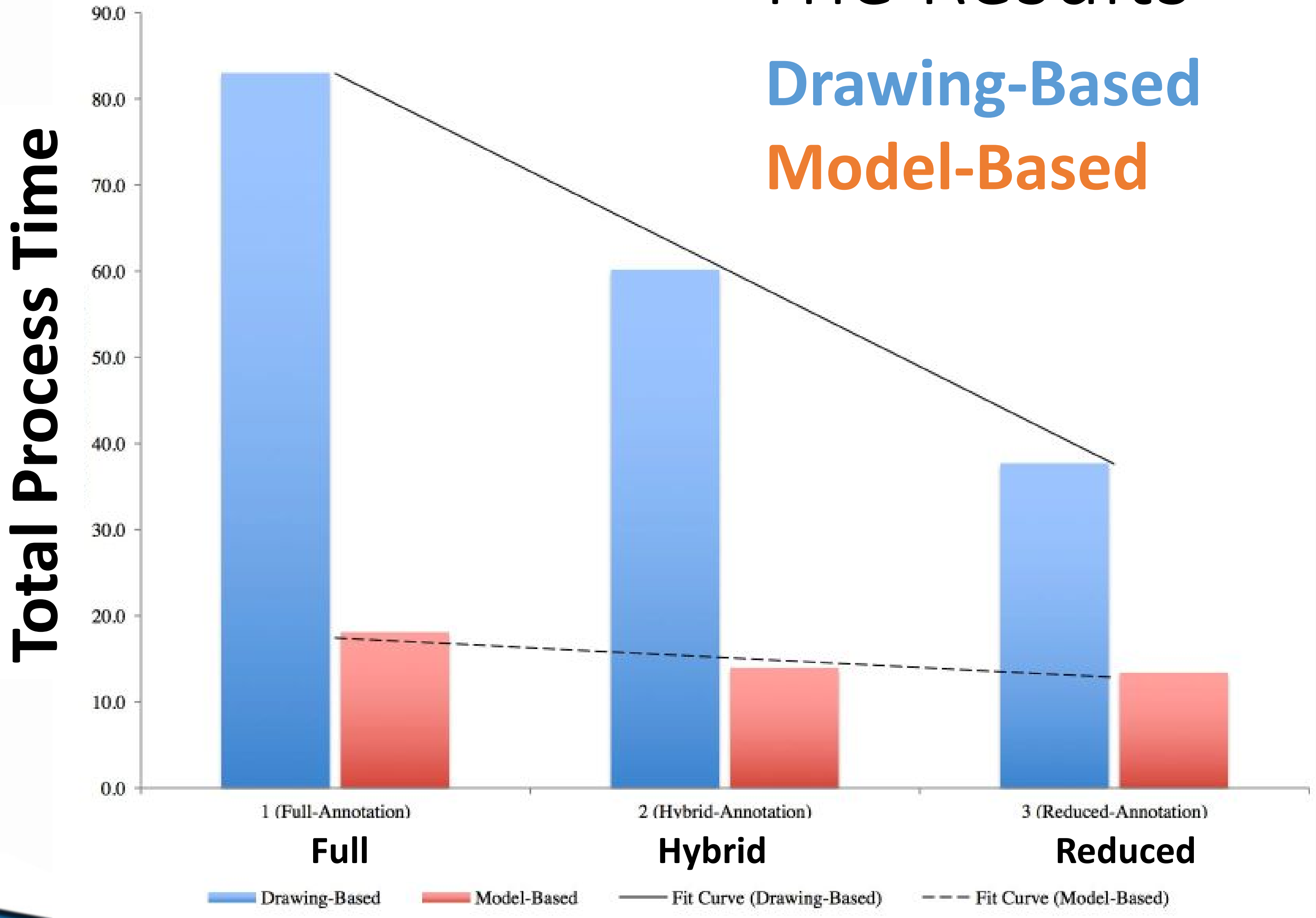






Hedberg Jr, T. D., Lubell, J., Fischer, L., Maggiano, L., & Barnard Feeney, A. (2016). Testing the Digital Thread in Support of Model-Based Manufacturing and Inspection. *Journal of Computing and Information Science in Engineering, 16*(2), 1-10. doi:10.1115/1.4032697

The Results



- Cycle-time based on design annotation, manufacture, and inspection cycle
- Avg. 60.3 hrs for drawing-based
- Avg. 18.5 hrs for model-based
- 74.8% average reduction

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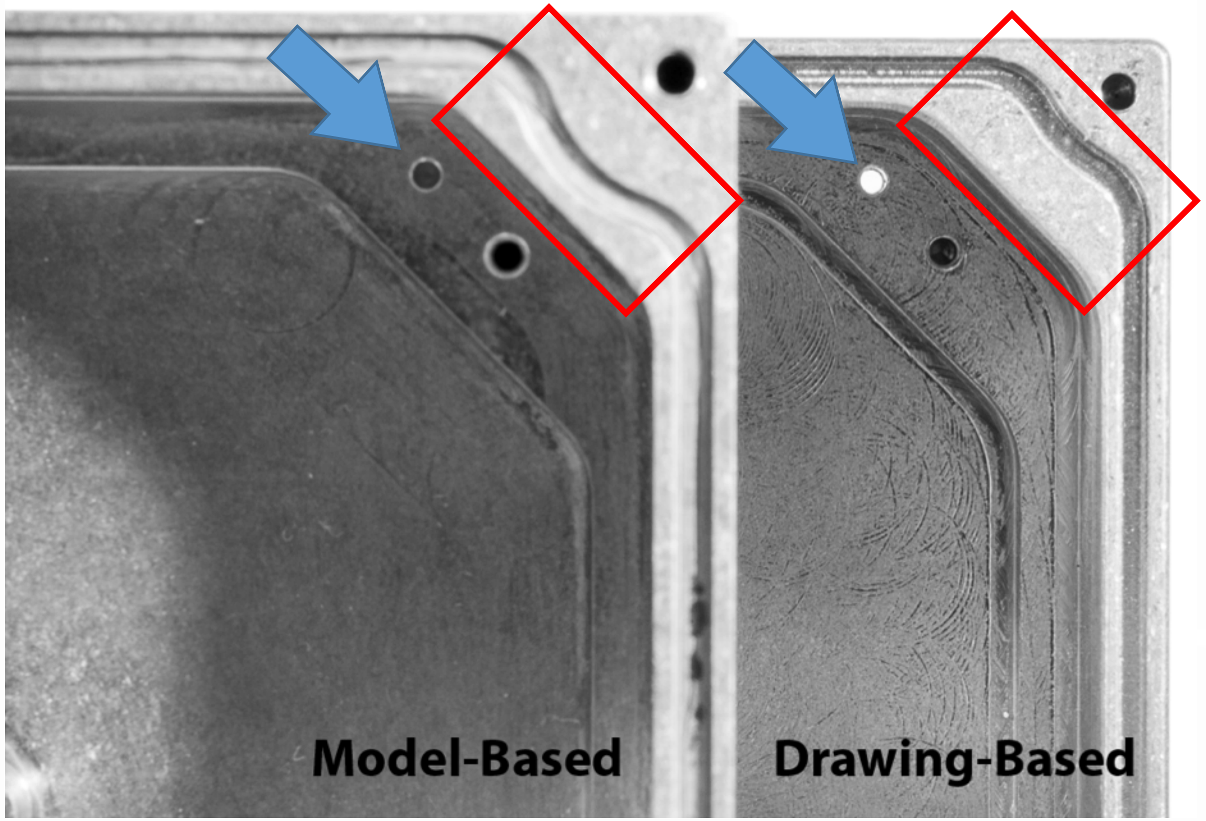
Results: Non-conformance



- Red box: gasket slot moved
  - Cause: Poor drawing interpretation, misunderstood where GD&T lines terminated
- Blue arrow: incorrect through hole
  - Cause: Depth call-out missed on drawing

Hedberg Jr, T. D., Lubell, J., Fischer, L., Maggiano, L., & Barnard Feeney, A. (2016). Testing the Digital Thread in Support of Model-Based Manufacturing and Inspection. *Journal of Computing and Information Science in Engineering, 16*(2), 1-10. doi:10.1115/1.4032697

More TTDT Observations

- No definition interpretation questions in model-based process
- The drawing-based supplier asked 12 questions for interpreting the drawing
  - Each question forced stop working
  - Average cycle-time for answering a question was 2.8 calendar days
  - Equated to a total of 34 calendar days of work stoppage due to product-definition interpretation using the 2D drawings
- Difference of 5.8 “active” days between the drawing-based process and model-based process
  - Model-based supplier delivered parts in approximately five weeks
  - Drawing-based supplier took approximately eight months to deliver parts

Design to Manufacturing and Inspection (D2MI)

Impact of standards-based interoperability on the supply chain

Rockwell Collins

GM — Geater Machining & Manufacturing, Co.

Mastercam

NIST

Mitutoyo

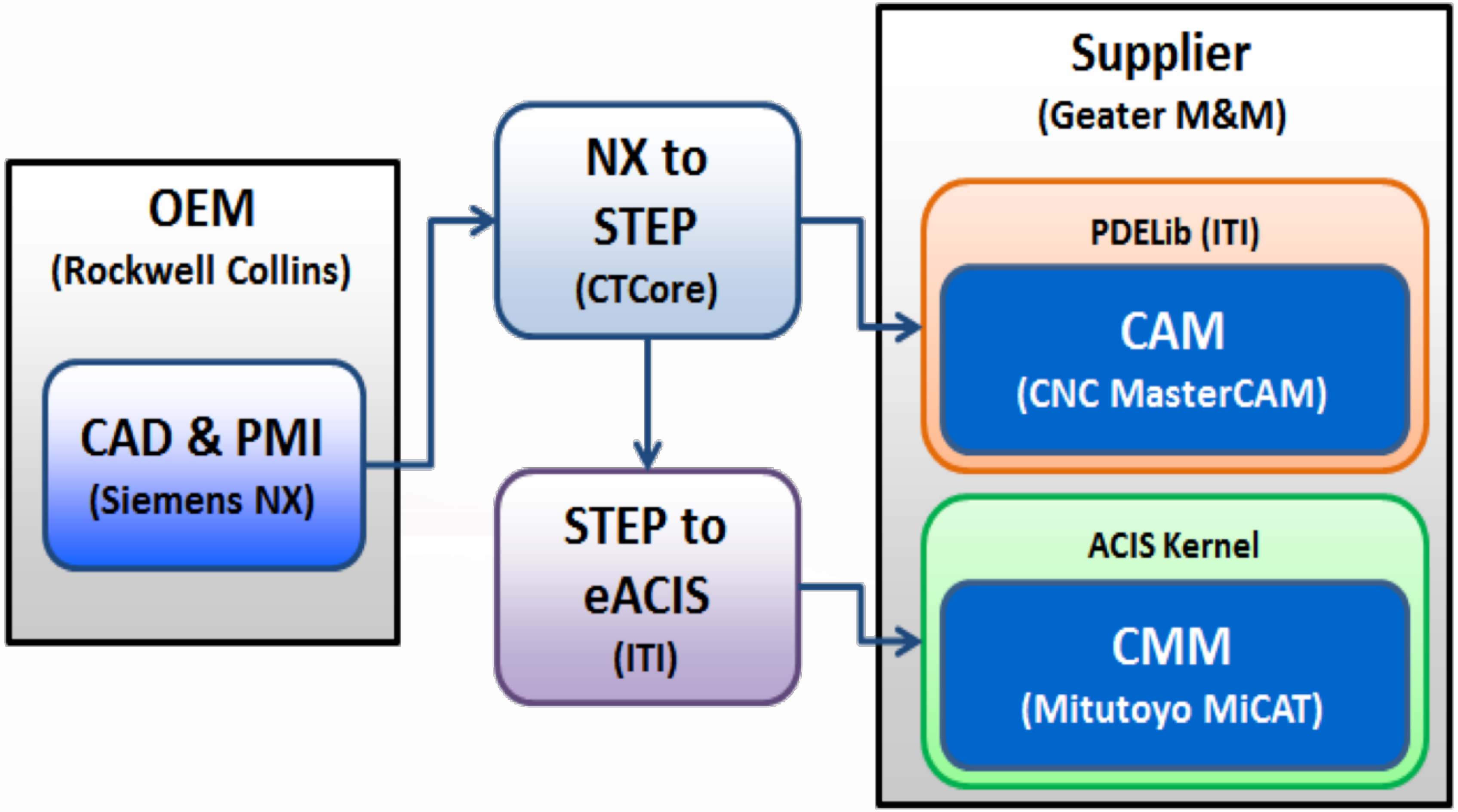
ITI — International TechneGroup

CORETECHNOLOGIE

ACCR — ADVANCED COLLABORATION CONSULTING RESOURCES

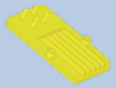
Fischer, K., Rosche, P., Trainer, A., Barnard Feeney, A., & Hedberg Jr, T. (2015). *Investigating the Impact of Standards-Based Interoperability for Design to Manufacturing and Quality in the Supply Chain* (NISTGCR 15-1009). Retrieved from Gaithersburg MD: http://www.nist.gov/manuscript-publication-search.cfm?pub_id=920033

D2MI Methodology



Trainer, A., Hedberg Jr, T., Barnard Feeney, A., Fischer, K., & Rosche, P. (2016). *Gaps Analysis of Integrating Product Design, Manufacturing, and Quality Data in the Supply Chain using Model-Based Definition.* Paper presented at the 2016 Manufacturing Science and Engineering Conference, Blacksburg VA.

CAD Results

CAD Metrics	Rolled Standoff 			Heat Sink 		
827-9999	**-903**	**-905**	**-907**	**-904**	**-906**	**-908**
2D PDF drawing	---	full dimension with 2D PMI annotation	key 2D PMI annotation only (PDD)	---	full dimension with 2D PMI annotation	key 2D PMI annotation only (PDD)
3D model	includes embedded PMI	not provided	with no embedded PMI	includes embedded PMI	not provided	with no embedded PMI
Number of PMI entities	23 (24*)	---	---	78 (90*)	---	---
CAD model creation (modified existing part)	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Model-embedded PMI	3.0 hours	---	---	6.0 hours	---	---
2D PDF drawing creation	0.5 hours	1.0 hours	0.7 hours	0.5 hours	2.4 hours	1.3 hours
CAD tool issue resolution and designer education	9.0 hours	0.5 hours	0.1 hours	4.9 hours	0.5 hours	0.1 hours
CAD model resolution to address downstream issues	2.3 hours + 4.5 hours to learn NX	---	---	3.0 hours + 1.3 hours to learn NX	original dwg missing dim – required ECO	---

* Original PMI entity count based on objects found in the NX Part navigator – eventually reduced count by issue resolution

CAM Results

CAM Metrics	Rolled Standoff 			Heat Sink 		
827-9999	**-903** 3D model with embedded PMI	**-905** 2D drawing fully annotated	**-907** 2D PMI drawing and 3D model	**-904** 3D model with embedded PMI	**-906** 2D drawing fully annotated	**-908** 2D PMI drawing and 3D model
CAM Process Preparation a) Gather information b) Analyze job c) Determine approach	**3.25 hours** a) 0.25 hours b) 0.50 hours c) 2.50 hours	**3.25 hours** a) 0.25 hours b) 0.50 hours c) 2.50 hours	**3.25 hours** a) 0.25 hours b) 0.50 hours c) 2.50 hours	**3.83 hours** a) 0.33 hours b) 0.50 hours c) 3.00 hours	**3.83 hours** a) 0.33 hours b) 0.50 hours c) 3.00 hours	**3.83 hours** a) 0.33 hours b) 0.50 hours c) 3.00 hours
CAM Setup a) Model preparation b) Pre-program setup	**0.45 hours** a) 0.00 hours b) 0.45 hours	**0.52 hours** a) 0.07 hours b) 0.45 hours	**0.45 hours** a) 0.00 hours b) 0.45 hours	**0.68 hours** a) 0.45 hours b) 0.23 hours	**0.64 hours** a) 0.52 hours b) 0.12 hours	**0.40 Hours** a) 0.28 hours b) 0.12 hours
CAM Programming a) Part programming b) Tooling preparation	**1.00 hours** a) 0.50 hours b) 0.50 hours	**1.00 hours** a) 0.50 hours b) 0.50 hours	**1.00 hour** a) 0.50 hours b) 0.50 hours	**3.23 hours** a) 3.01 hours b) 0.22 hours	**3.13 hours** a) 2.75 hours b) 0.38 hours	**2.30 hours** a) 2.08 hours b) 0.22 hours
CAM Verification a) Create work instructions (setup sheets) b) Review process (Run VERICUT)	**0.15 hours** a) 0.10 hours b) 0.05 hours	**0.15 hours** a) 0.10 hours b) 0.05 hours	**0.15 hours** a) 0.10 hours b) 0.05 hours	**0.42 hours** a) 0.32 hours b) 0.10 hours	**0.50 hours** a) 0.35 hours b) 0.15 hours	**0.53 hours** a) 0.35 hours b) 0.18 hours
Total	**4.85 hours**	**4.92 hours**	**4.85 hours**	**8.16 hours**	**8.10 hours**	**7.06 hours**

CMM Results

CMM Metrics	Rolled Standoff 			Heat Sink 		
827-9999	**-903** 3D model with embedded PMI	**-905** 2D drawing fully annotated	**-907** 2D PMI drawing and 3D model	**-904** 3D model with embedded PMI	**-906** 2D drawing fully annotated	**-908** 2D PMI drawing and 3D model
CMM Process Preparation	Unable to perform automated inspection process due to physical size limits of the available CMM equipment. The part features were too small for the CMM probe to measure. These test parts were inspected manually.			**0.10 hours**	**0.50 hours**	**0.75 hours**
CMM Setup				**0.10 hours**	**0.75 hours**	**1.00 hour**
CMM Programming				**0.50 hours**	**4.76 hours**	**4.75 hours**
CMM Verification a) Verify information b) Verify for collisions				**0.30 hours** a) 0.15 hours b) 0.15 hours	**1.00 hours** a) 0.50 hours b) 0.50 hours	**1.00 hour** a) 0.50 hours b) 0.50 hours
Inspection a) CMM inspection b) Manual inspection	**0.50 hours** a) 0.00 hours b) 0.50 hours	**0.25 hours** a) 0.00 hours b) 0.25 hours	**0.25 hours** a) 0.00 hours b) 0.25 hours	**0.70 hours** a) 0.20 hours b) 0.50 hours	**0.40 hours** a) 0.20 hours b) 0.20 hours	**0.40 hours** a) 0.20 hours b) 0.20 hours
CMM Data Analysis				**0.50 Hours**	**0.50 hours**	**0.50 hours**
Total Time	**0.50 hours**	**0.25 hours**	**0.25 hours**	**2.20 hours**	**7.91 hours**	**8.40 hours**

D2MI Findings: Tools

- Rules should be implemented in CAD systems to better align model creation with the downstream-machine-interpretable expectations
- Verification tools are needed to ensure that best practices have been followed prior to the release of models for downstream consumption
- Additional work is needed in order to overcome remaining deficiencies in CAM/CAI kernels to enable embedded-PMI exchange

D2MI Findings: Standards

- Lack of support for "unless otherwise specified" increases cycle time for both the data authors and data consumers
- Surface finish is lacking for support of manufacturing and inspection
- Addition of manufacturing features in models will increase efficiency for manufacturing operations

D2MI Findings: Process

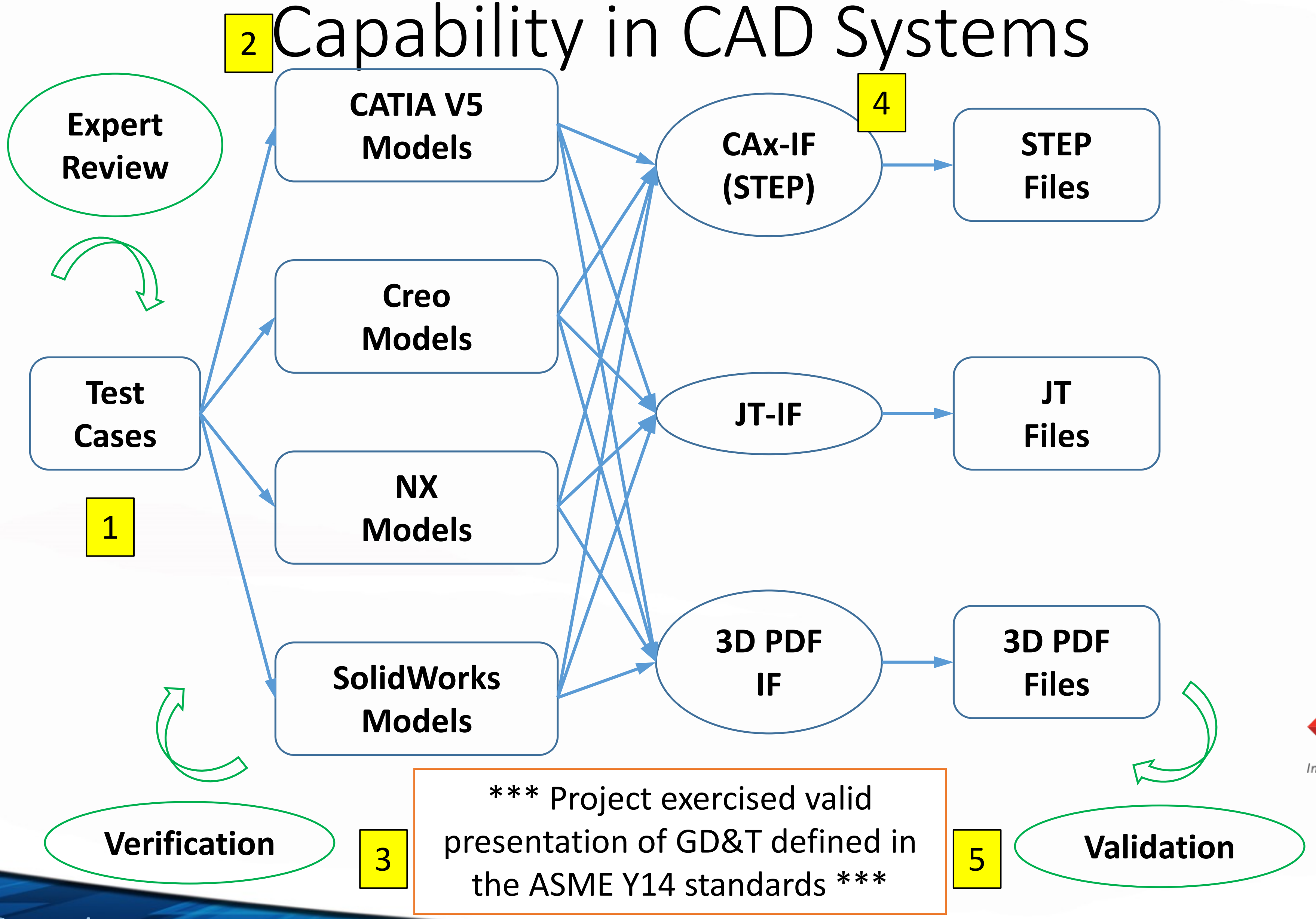
- Missing dimensions in 2D data set highlights value of 3D model use

- Designer education is not yet aligned with requirements for downstream PMI consumption

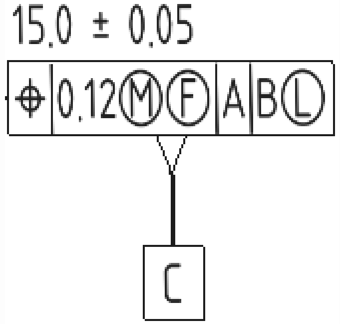
- Potential exists for:
  - automating AS9102 population,
  - developing a visual presentation that ties metrology results and MBD,
  - and providing metrology results feedback to upstream users for analysis and prediction

Related value-added works

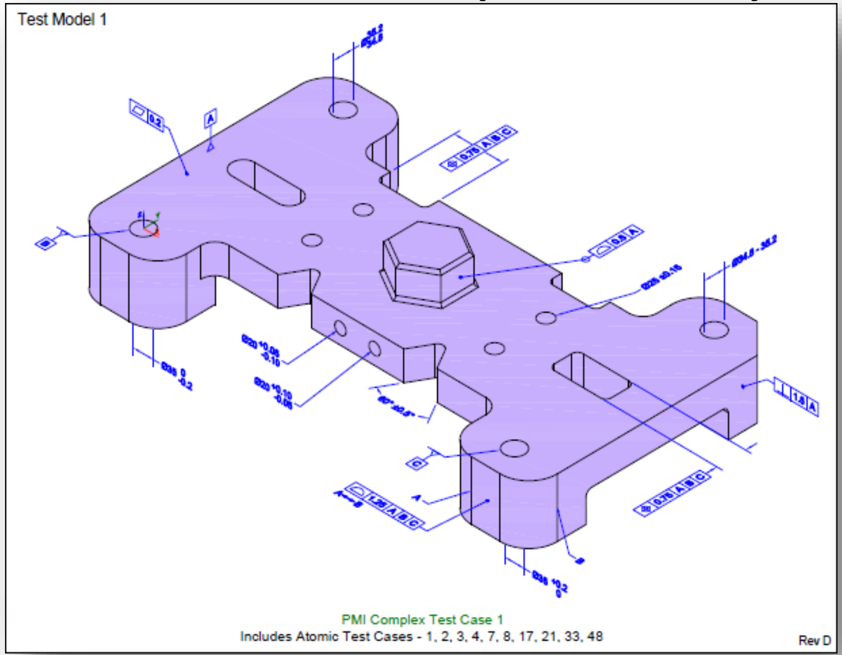
Measuring the PMI Modeling Capability in CAD Systems



Measuring the PMI Modeling Capability in CAD Systems



Example presentation of GD&T annotation

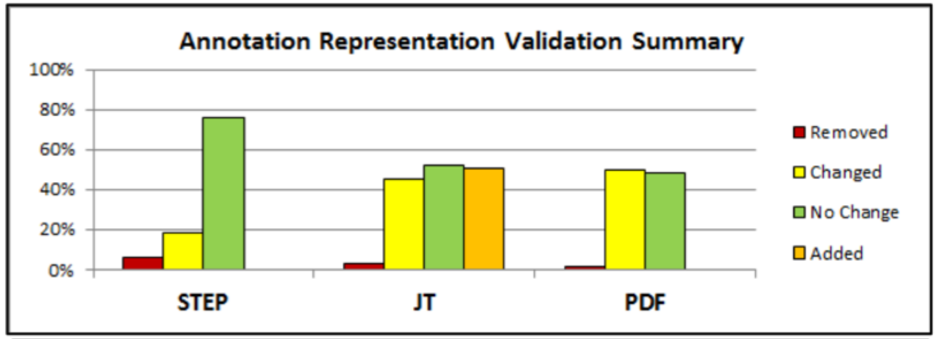


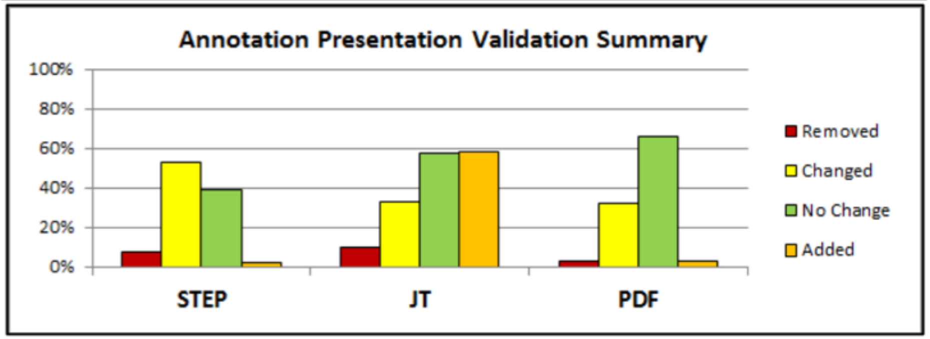
Example Test Case

Overview of CAD Capabilities

	CAD A	CAD B	CAD C	CAD D
No Limitations	85%	74%	69%	67%
Presentation Limitations only	2%	10%	18%	14%
Representation Limitations	13%	16%	13%	19%
Representation Level	87%	84%	87%	81%

Overview of Neutral Capabilities





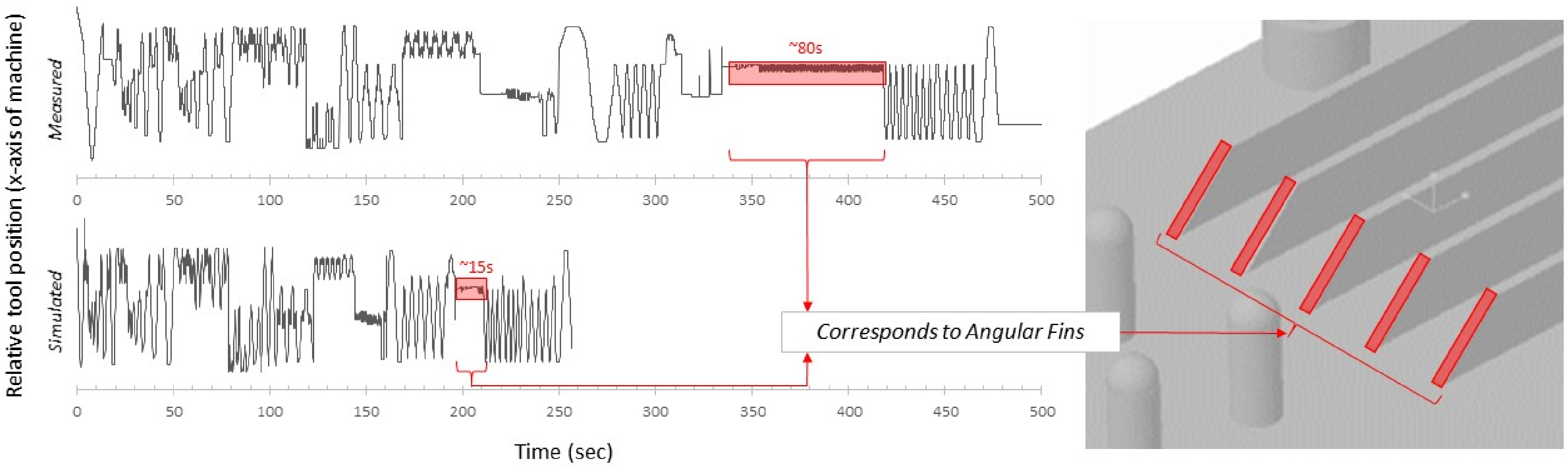
Impacts:

- Influencing direction of ASME Y14.41 and Y14.41.1
- Closing gaps in STEP AP242, PDF-PRC, JT, and QIF

Reports, models, and more at: http://go.usa.gov/mGVm

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

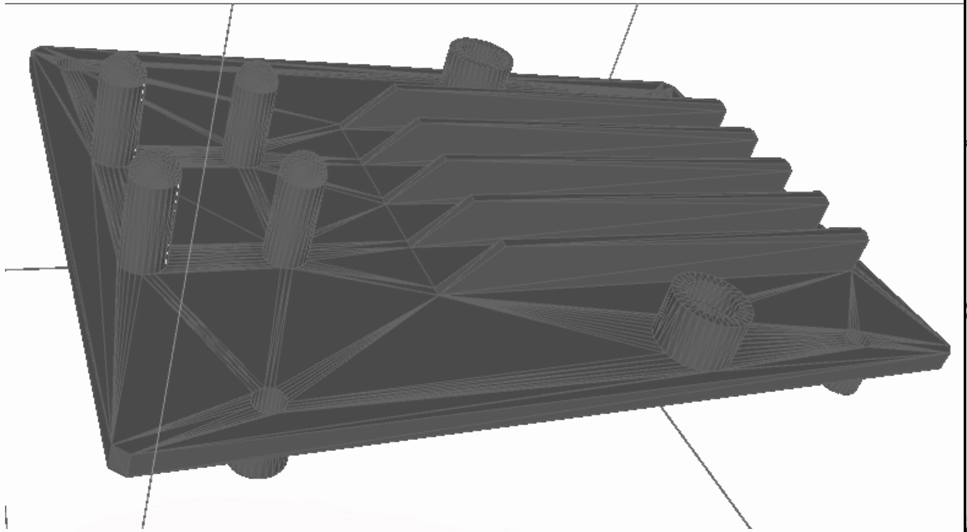


system insights

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

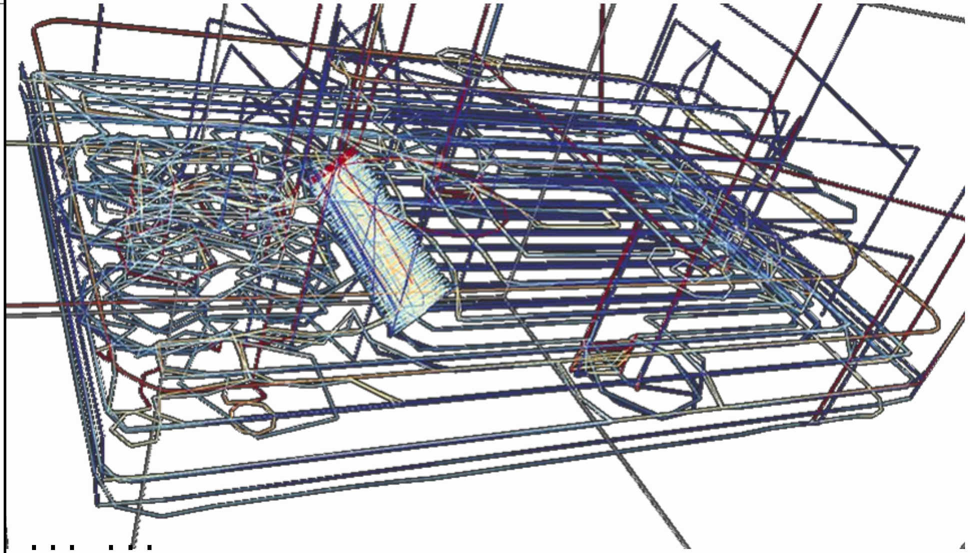
Present and Represent Activities

Design Data
(ISO 10303 – STEP AP242)



```
... ...
#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);
... ...
```

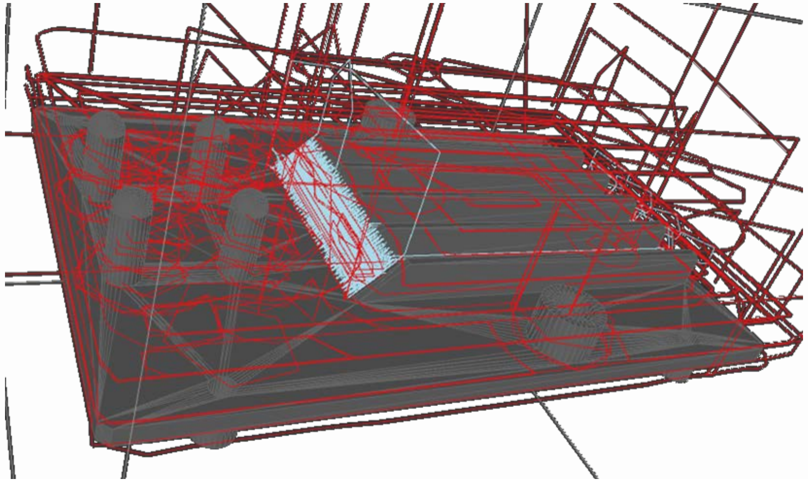
Manufacturing Data
(MTConnect & QIF)



```
... ...
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...
... ...
```

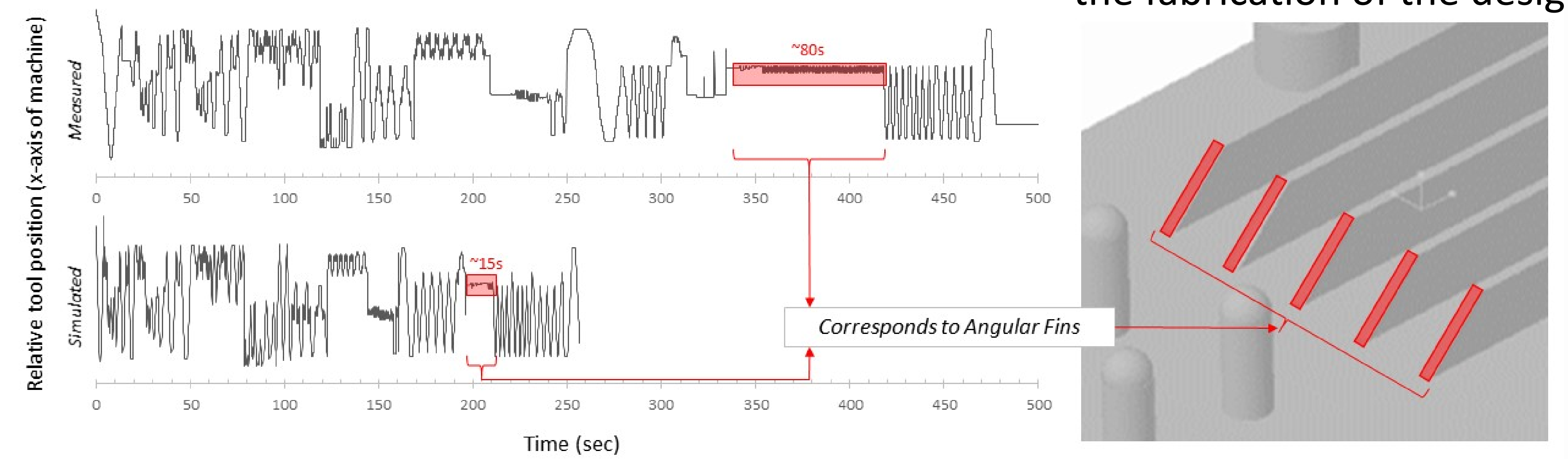
Feng, S. C., Bernstein, W. Z., Hedberg Jr, T., & Barnard Feeney, A. (Accepted, In-press). Towards Knowledge Management for Smart Manufacturing. *Journal of Computing and Information Science in Engineering*.

Apply Data Analytics & Build Knowledge



Cause for mismatch:

- 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



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