JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

‘The Cost of Enabling the Digital Thread’

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Agenda

- Background
- Purpose
- Assumptions
- Method
  - Data Synopsis
  - Data Normalization Synopsis
- Analysis
- Conclusion
- Future Research
- Questions?

Background - Definitions

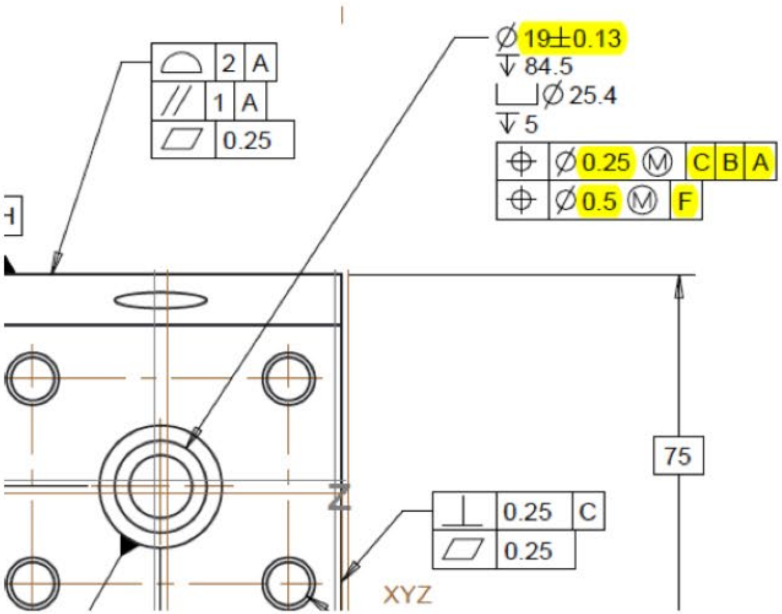
MBE – “an organization and/or an operation that uses model-based definitions (MBD) for the purpose of commissioning, operating, servicing, and decommissioning a product.” (Hedberg et al, 2017)

MBD – “The practice of using 3D datasets containing the exact solid representation, associated 3D geometry and 3D annotations of a product’s dimensions, tolerances, materials, finishes and other notes to specify a complete product definition.” (MIL-STD-31000; ASME Y14.41)”

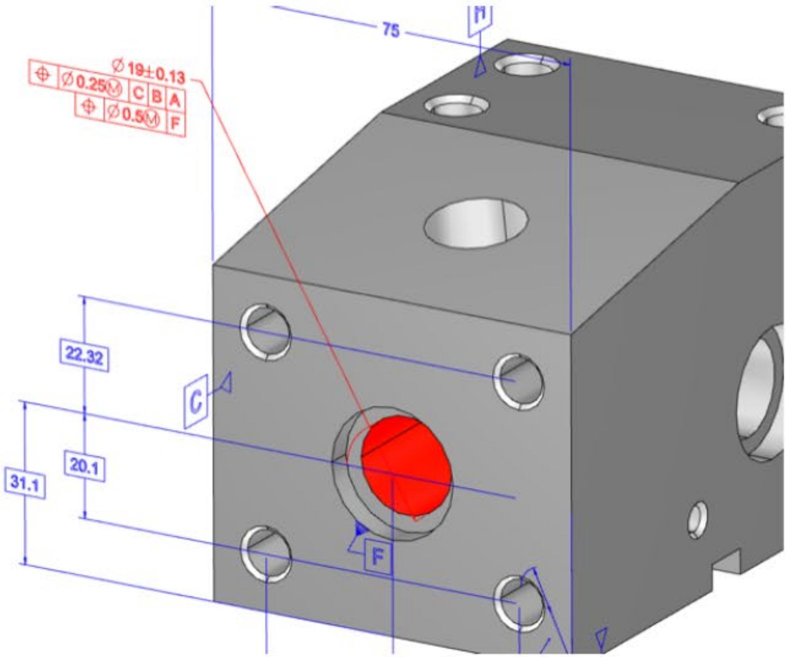
Digital Thread – a method “to convey the data flows between engineering, manufacturing, business processes, and across supply chains.” (Hedberg et al, 2016)

Background – MBD/MBE

2D Drawing vs. 3D MBD



(A)



(B)

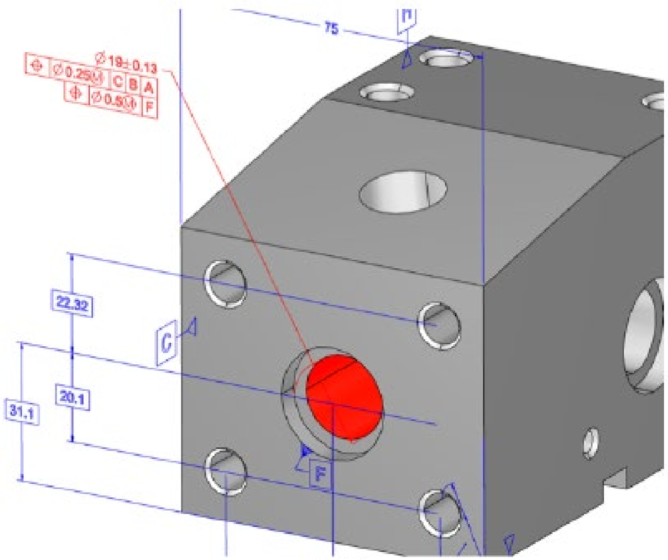
Graphics obtained from Hedberg et al, 2016

Background – MBD/MBE

MBD

For Human Consumption

For Computer Consumption



(B)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<?xml version ="1.0" encoding="UTF-8"?>
<ModelTree3D Version = "1.0">
  <Node Name="DIM">
    <Property Name="cadEntityId" Value="1339"/>
    <Property Name="dimensionText" Value="{0: n }{1:@D}{2: # 0.13}"/>
    <Property Name="dimensionType" Value="DIMTYPE_DIAMETER"/>
    <Property Name="displayedValue" Value="19.000"/>
    <Property Name="gtl_gtolType" Value="GTOLTYPE_POSITION"/>
    <Property Name="gtl_isComposite" Value="false"/>
    <Property Name="gtl_isOverallTolerance" Value="true"/>
    <Property Name="gtl_isPerUnitTolerance" Value="false"/>
    <Property Name="gtl_materialCondition" Value="GTOLMATCOND_MMC"/>
    <Property Name="gtl_overallToleranceValue" Value="0.250000"/>
    <Property Name="gtl_primaryBasicDatumName" Value="C"/>
    <Property Name="gtl_secondaryBasicDatumName" Value="B"/>
    <Property Name="gtl_showAllAroundSymbol" Value="false"/>
    <Property Name="gtl_showDiameterSymbol" Value="true"/>
```


(C)

Graphics obtained from Hedberg et al, 2016

Background – Existing Research

'Testing the Digital Thread in Support of Model-Based Manufacturing and Inspection'

(Hedberg et al, 2016)

- Compared 2D DWG processes vs 3D MBD processes
  - Design -> Manufacture -> Inspect (for mechanical components)
- Three different test cases of varying level of annotations
  - Full, hybrid, and reduced annotations
- Findings: **3D MBD more efficient overall, but can be more labor some during design phase**

Background – Existing Research

Graphic obtained from Hedberg et al, 2016

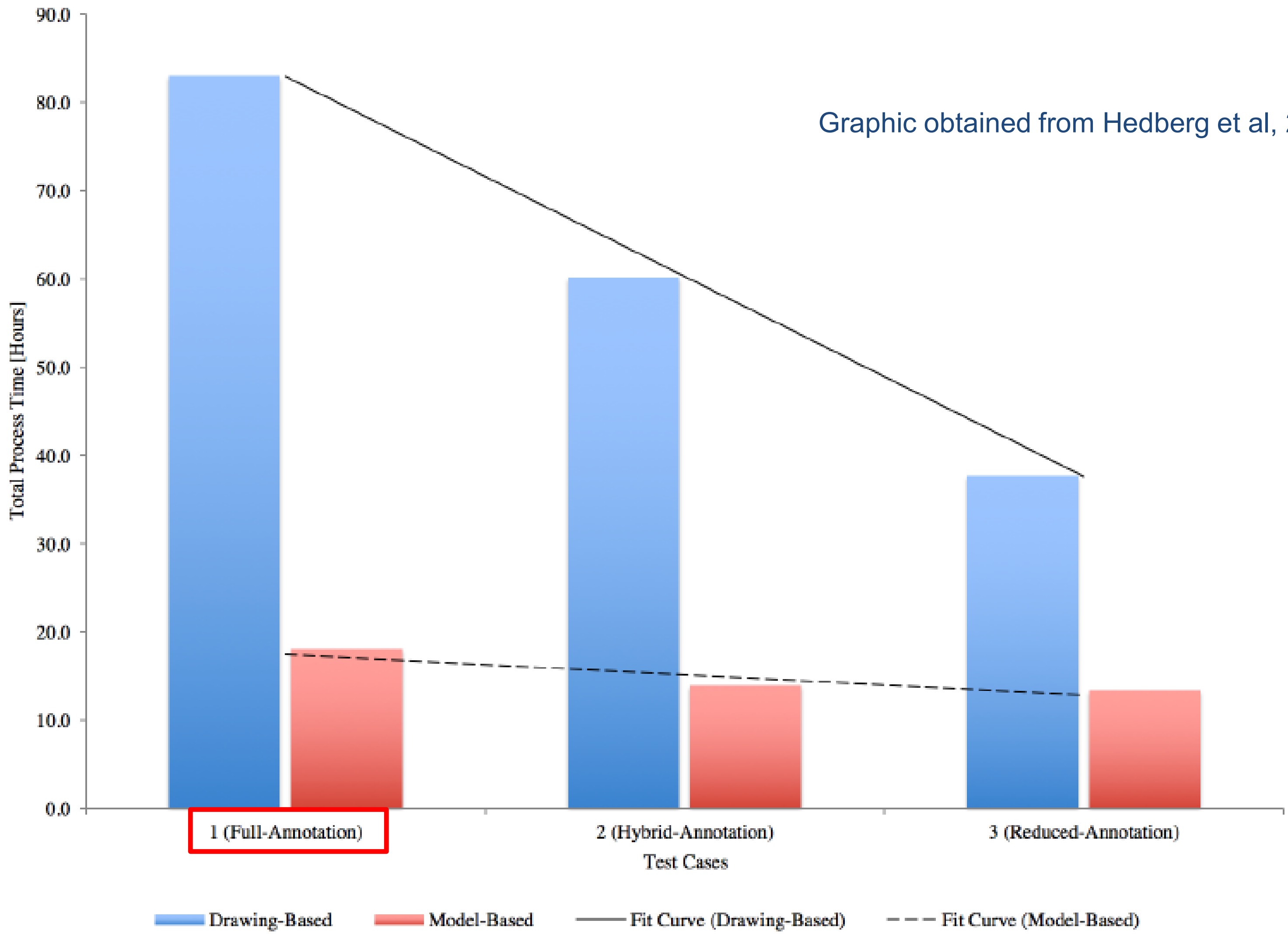


Fig. 8. Comparison of drawing-based and model-based processes

Background – Existing Research

Table 2. Observed time to annotate the design definition

Test Case	Number of Characteristics	Drawing Time [hrs]	MBD Time [hrs]	Delta [hrs]
1	84	3.1	8.7	5.6
2	57	2.7	2.1	-0.6
3	53	2.2	2.0	-0.2
Total	194	7.9	12.8	4.9

Graphic obtained from Hedberg et al, 2016

Purpose

- Fill literature gaps
  - Findings supported by **quantitative evidence** are limited
  - Findings supported by **real-world/non-piloted** evidence are limited
  - Quantitative analysis from a **Systems Engineering** use case/viewpoint
- Validate/Extend existing work
- Focus on ROI & potential counterproductiveness

Assumptions

- model organization schema for MBD data include annotations and no attributes (as defined by ASME Y14.47)
- the data sets best compare to the full annotations test case of Hedberg et al.'s 2016 [2] study
- model organization schema for the MBD data sets are for human consumption
- the scope of all data sets is inclusive of annotating the design definition only
- learning curves are non-existent as both the 2D DWG and 3D MBD are not new to the designers/engineers
- both the 2D DWGs and 3D MBD geometric models were created in the same CAD environment using the same business rules
- both the 2D DWGs and 3D MBD have dimensions and tolerances in accordance with ASME Y14.5

Method

Stepped approach conducted in three parts:

1) Validation of existing research on MBD
   - Comparison of 2D vs 3D Design Effort for Mechanical Components using real-world data (raw and normalized data)

2) Extending the existing research…
   - Comparison of 2D vs 3D Design Effort for Varying Types of Drawing Formats using real-world data (raw and normalized data)

3) Extending the existing research…
   - Comparison of the trends between Part 1 and Part 2

Data Synopsis

The data being used is suitable for the comparison as…

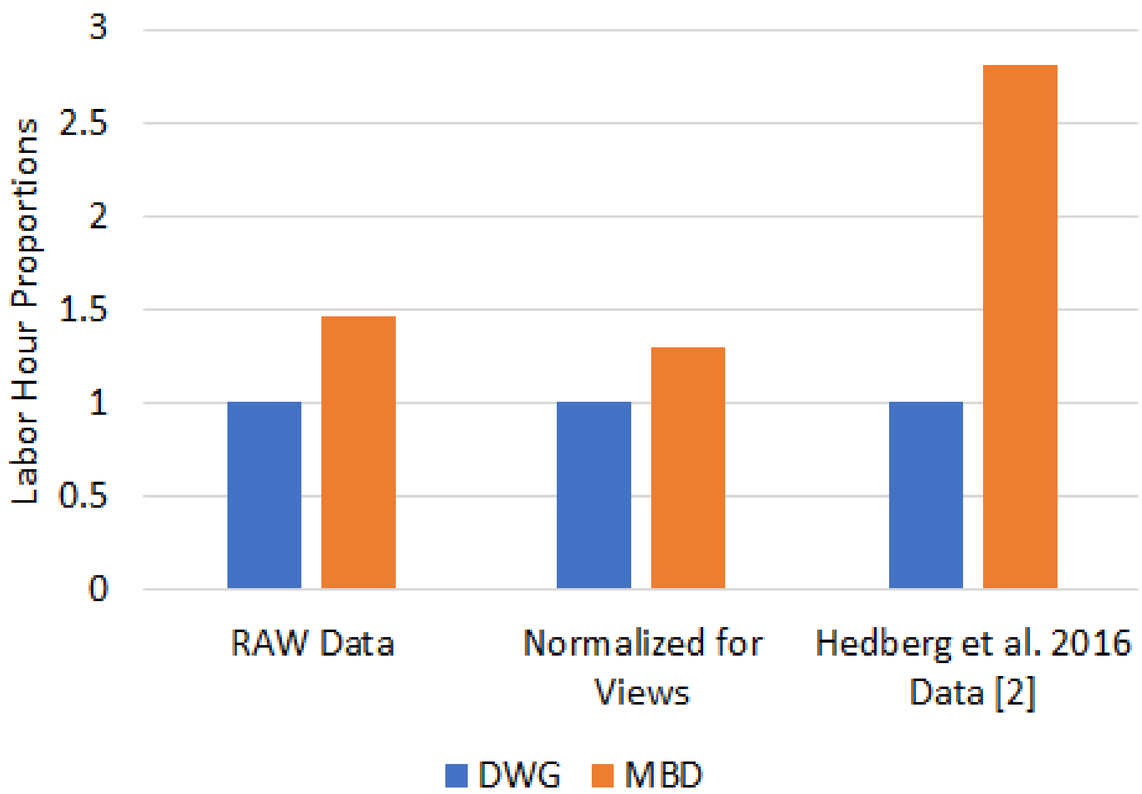
- products for the 2D DWG and 3D MBD practices are of similar content, size and complexity
- 2D DWG data were annotated using MIL-STD-100G and ASME Y14.5
- 3D MBD data were annotated using MIL-STD-31000A and ASME Y14.5

Data Normalization Synopsis

- Part 1 & 3
  - Normalized for number of views
- Part 2
  - Normalized for number of views
  - Normalized for number of parts
- Using ASME Y14.47 it was determined that the MBD was ...
  - maturity states of M3 (i.e. production)
  - geometry states of G3 (full)
  - annotation and attribute states of A3 (full)

Analysis

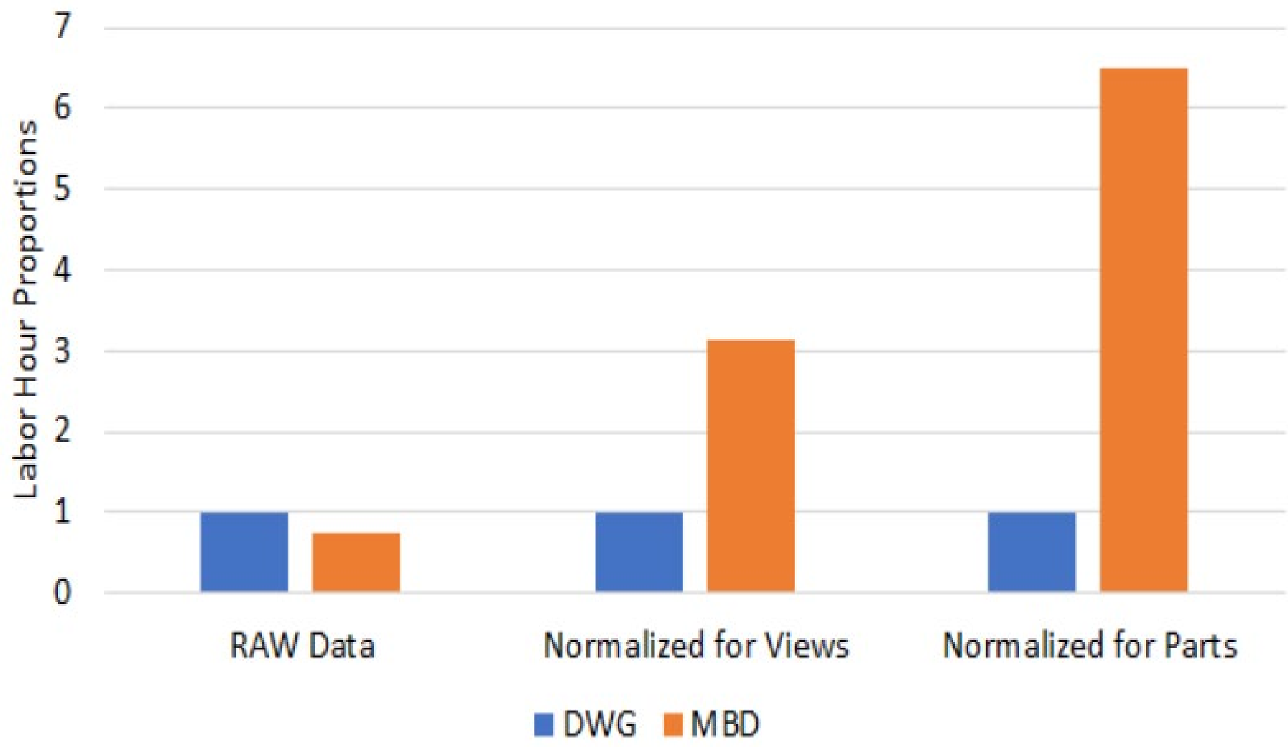
Part I – Validate Hedberg et al, 2016 findings



Comparison of 2D DWG and 3D MBD Design Efforts for Components

Analysis

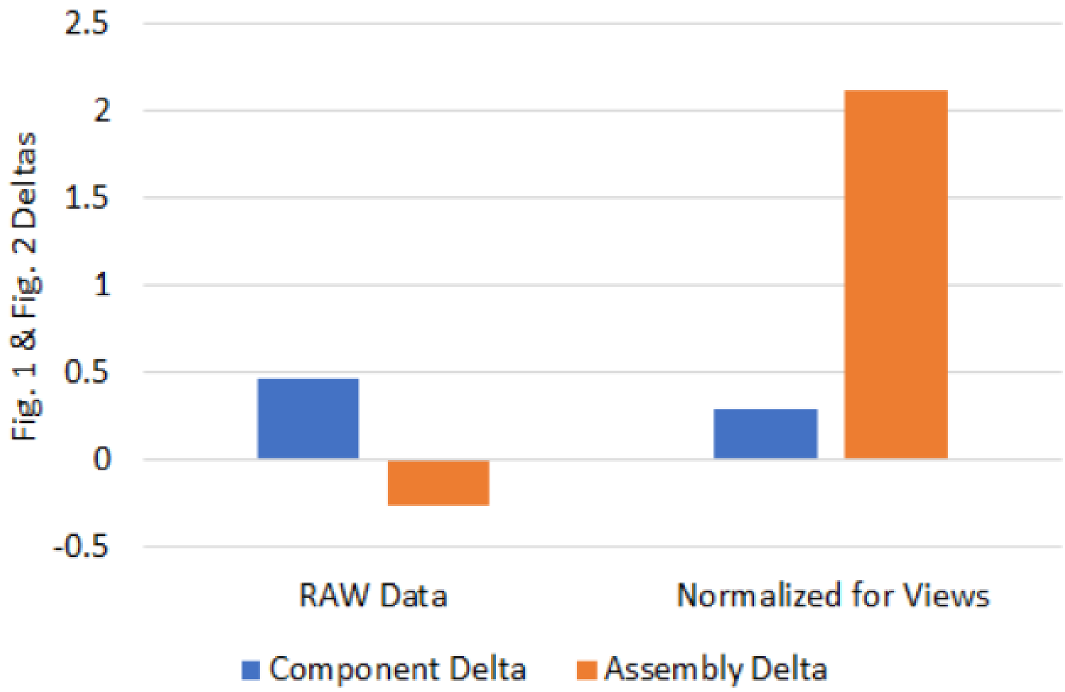
Part 2 – Extending existing research



Comparison of 2D DWG and 3D MBD Design Efforts for Assemblies

Analysis

Part 3 – Comparison of the trends between Part 1 and Part 2a



Comparison of 2D vs 3D Proportion Trends Between Components and Assemblies

Conclusion

- Part 1
  - Partially validates Hedberg et al, 2016's work
  - Sets a benchmark for the study and validates data
- Part 2
  - Suggests the trends found by Hedberg et al, 2016 are consistent at the assembly level
- Part 3
  - Inconclusive due to affects of unknown variables

Future Research

Future Research

- **Compare 2D DWG vs 3D MBD assemblies in a controlled environment**
- Compare 2D DWG vs 3D MBD for varying engineering disciplines
- **Extend the research of this paper to the manufacturing and inspection phases to calculate ROI**
- Investigate the benefits of MBD throughout the change process

QUESTIONS?

References

- T. Hedberg, J. Lubell, L. Fischer, L. Maggiano and A. B. Feeney, "Testing the digital thread in support of model-based manufacturing and inspection," Journal of Computing and Information Science in Engineering, p. 16(2), 2016.
- Department of Defense, Department of Defense Standard Practice for Engineering Drawings: MIL-STD-100G, 1997.
- American Society of Mechanical Engineers, Dimensioning and Tolerancing. ASME Y14.5-2009, 2009.
- Department of Defense, Department of Defense Standard Practice Technical Data Packages: MIL-STD-31000A, 2013.
- American Society of Mechanical Engineers, "Model Organization Practices ASME Y14.47-2019," 2019.