



EXTENDING THE CAPABILITIES OF DATA ELEMENT MAPPING AND ANALYSIS FOR ADVANCED MANUFACTURING

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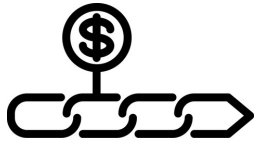
AUBURN UNIVERSITY

Samuel Ginn College of Engineering

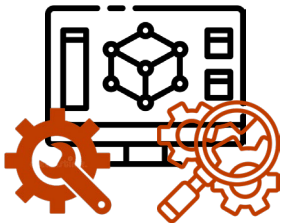
OVERVIEW



Digital Thread Gaps and Challenges



Value Chains



Approach and Case Studies



Summary and Future Work

DEFINING THE DATA

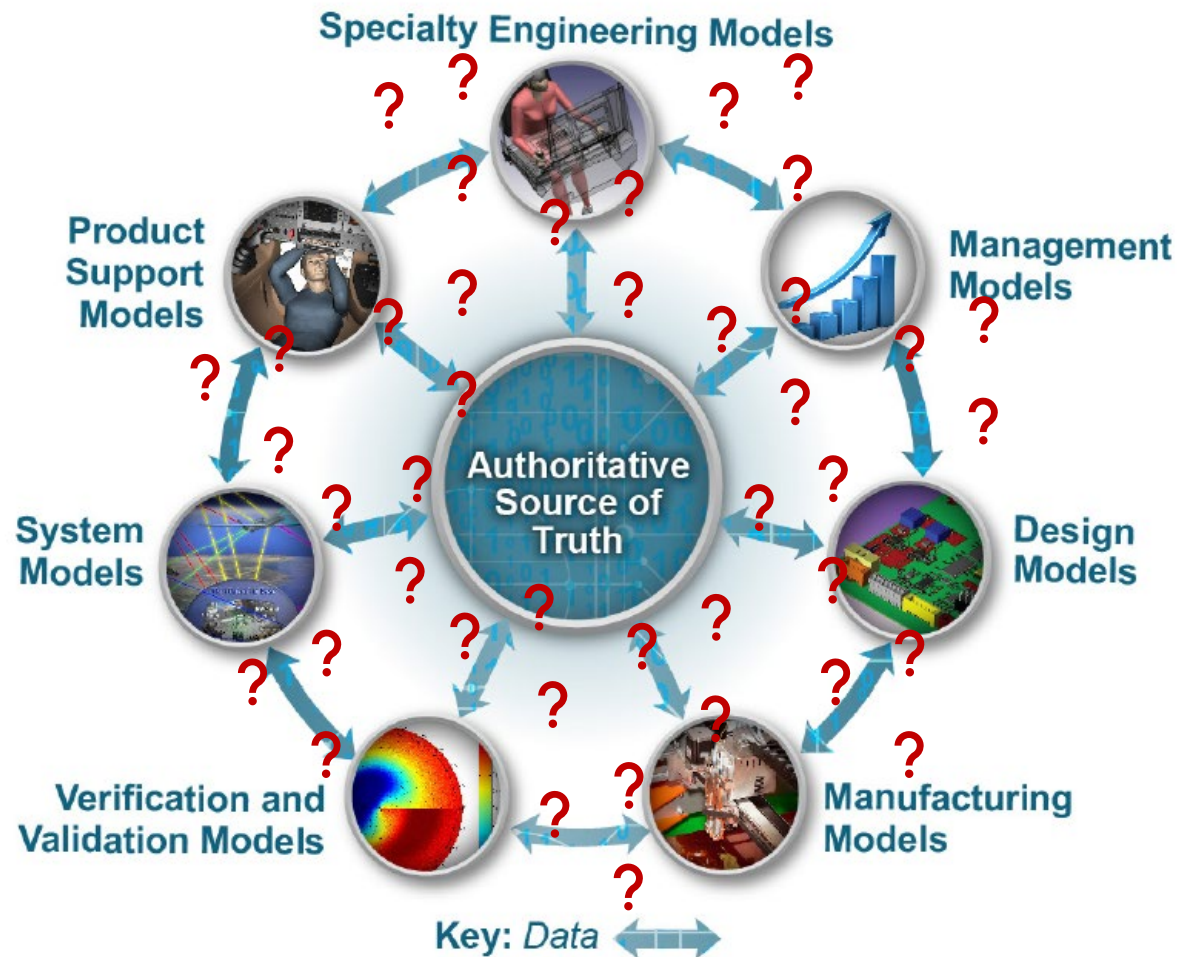


Figure 1: Adapted from Authoritative Source of Truth Figure from 2018 DoD Digital Engineering Strategy.

The Problem ^{[1][2]}:

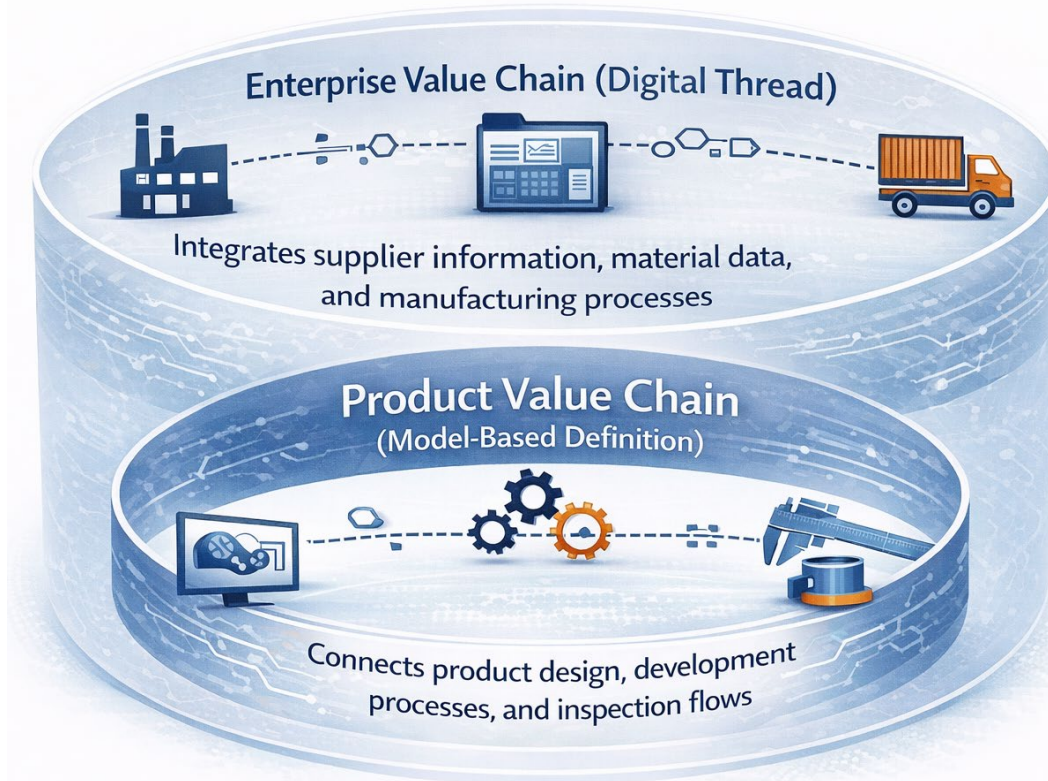
- Around 90-95% of data handling is unknown and nonstandard (hidden to the organization).

The Question:

- How can we establish the Digital Thread (including Model-Based Definition) if most data is tribal and undocumented?

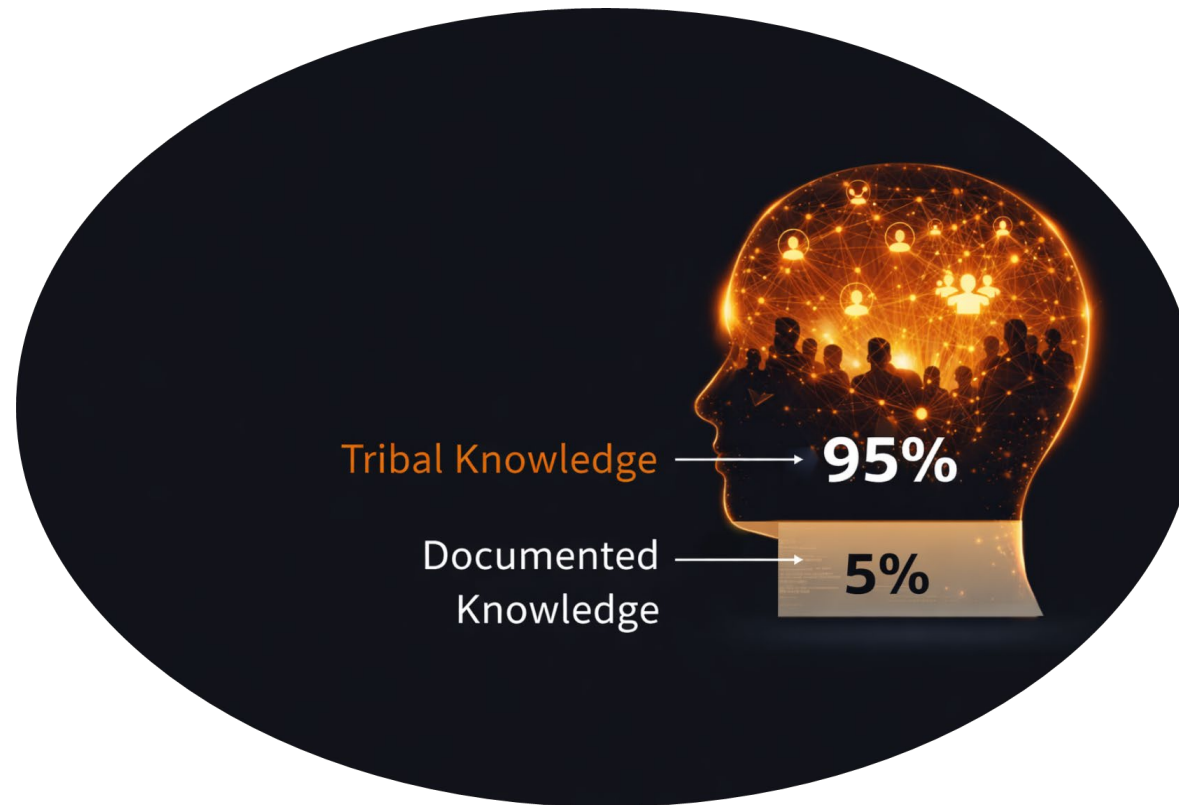
DIGITAL THREAD AS AN ENABLER OF VALUE CHAIN [1]

Value Chains	Description
Enterprise Value Chain	The end-to-end organizational flow of value creation across suppliers, materials, manufacturing, logistics, and operational decision-making, enabled by the digital thread.
Product Value Chain	A subset of the enterprise value chain that connects product design, engineering development, manufacturing execution, inspection



GAPS IN THE DIGITAL THREAD

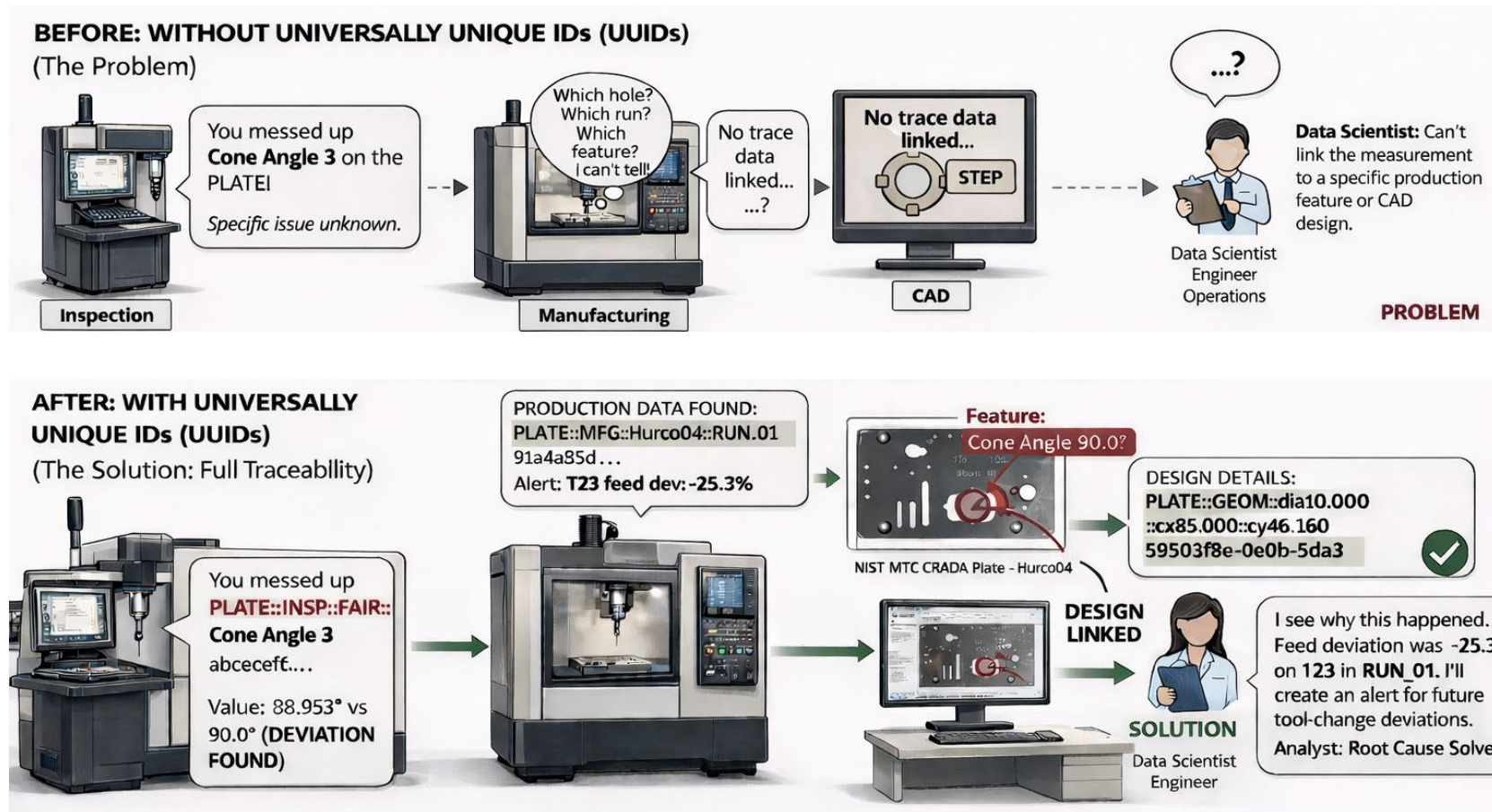
- Enterprise Value Chain – Many companies have created a value chain for product flow but have not performed value chaining for data flows. There is a need to improve insights and reduce redundancy and waste in data collection.



GAPS IN THE DIGITAL THREAD

- Product Value Chain – Much of our product data remains only loosely integrated with the manufacturing processes used to produce the product.

Gaps in Data Flows [2]





IMPLEMENTING THE DIGITAL THREAD

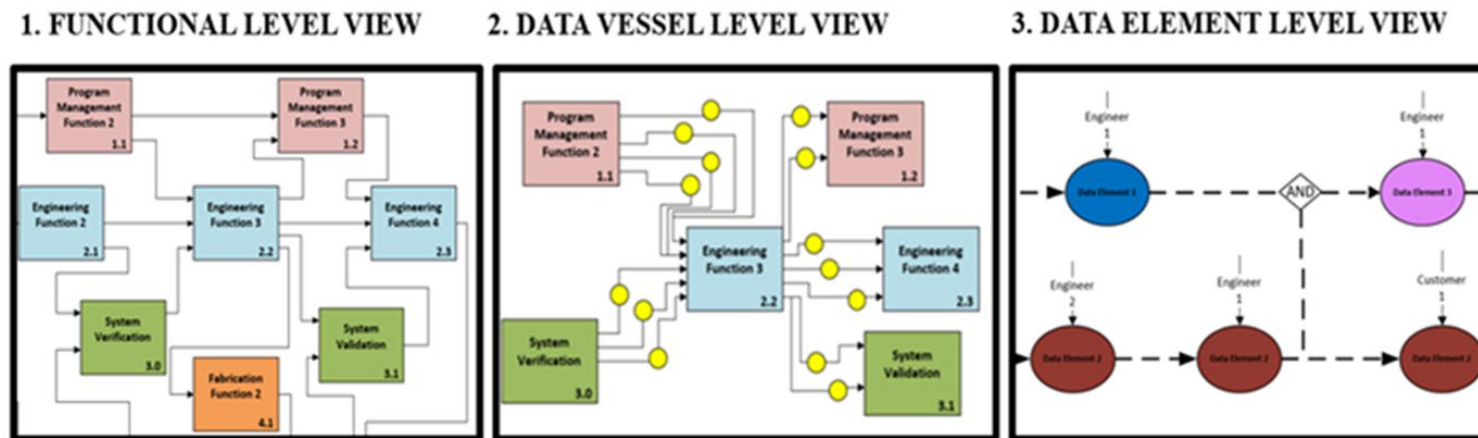
CHALLENGE

1. Capturing tribal knowledge across the manufacturing enterprise and transforming it into actionable insights for continuous improvement
2. Integrating product and process/operational characteristics into a unified, interoperable model

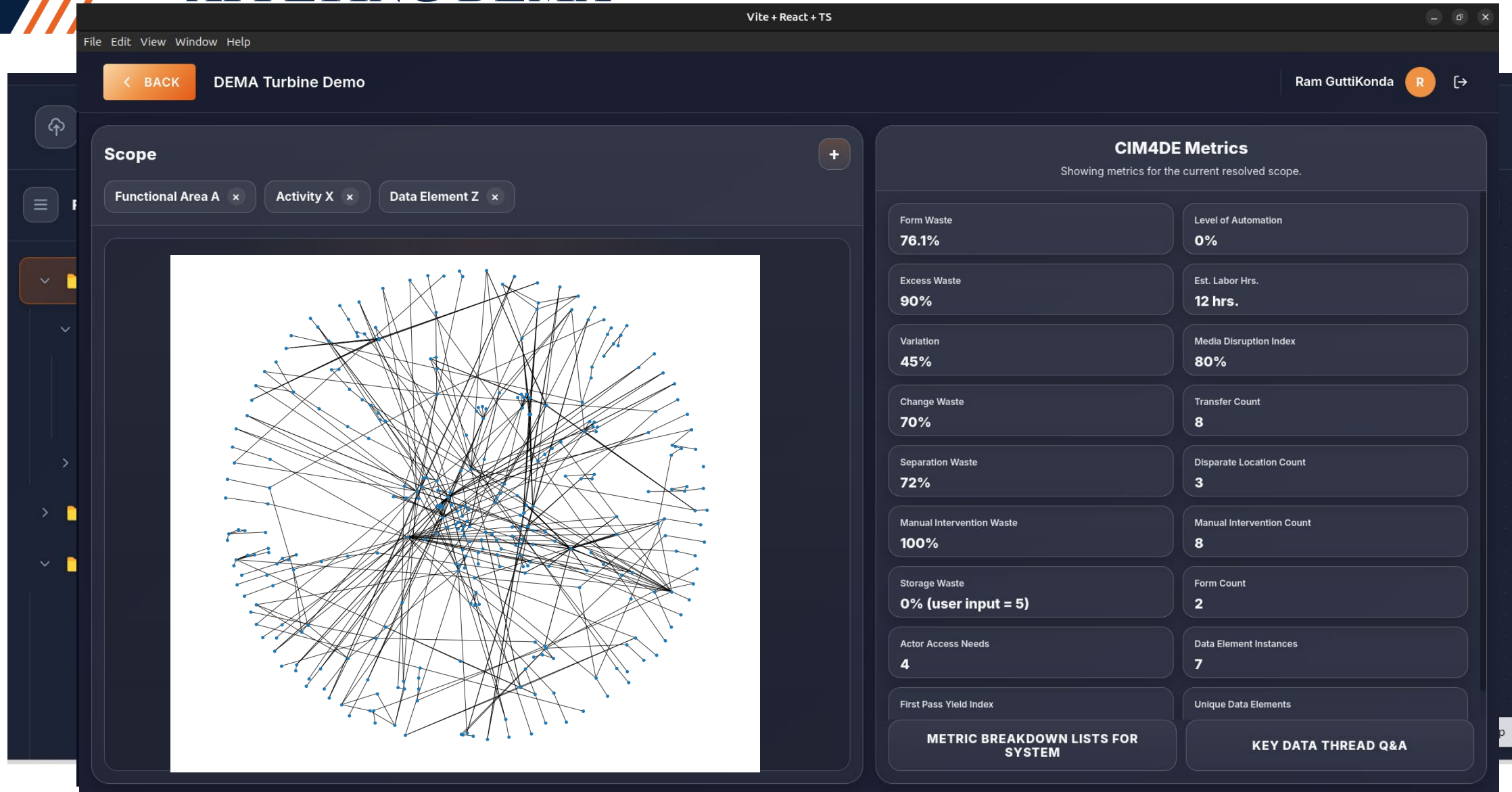
CONTRIBUTIONS

1. DEMA Contribution – Maps enterprise workflows and data dependencies to generate operational digital models for decision support
2. MBD Contribution – Integrates design, manufacturing, and inspection data into a unified lifecycle model

- Combines traditional functional analysis, systems engineering elicitation, and novel data mapping techniques to provide a holistic view of a system's data and information flows down to the data element level.



APPLYING DEMA

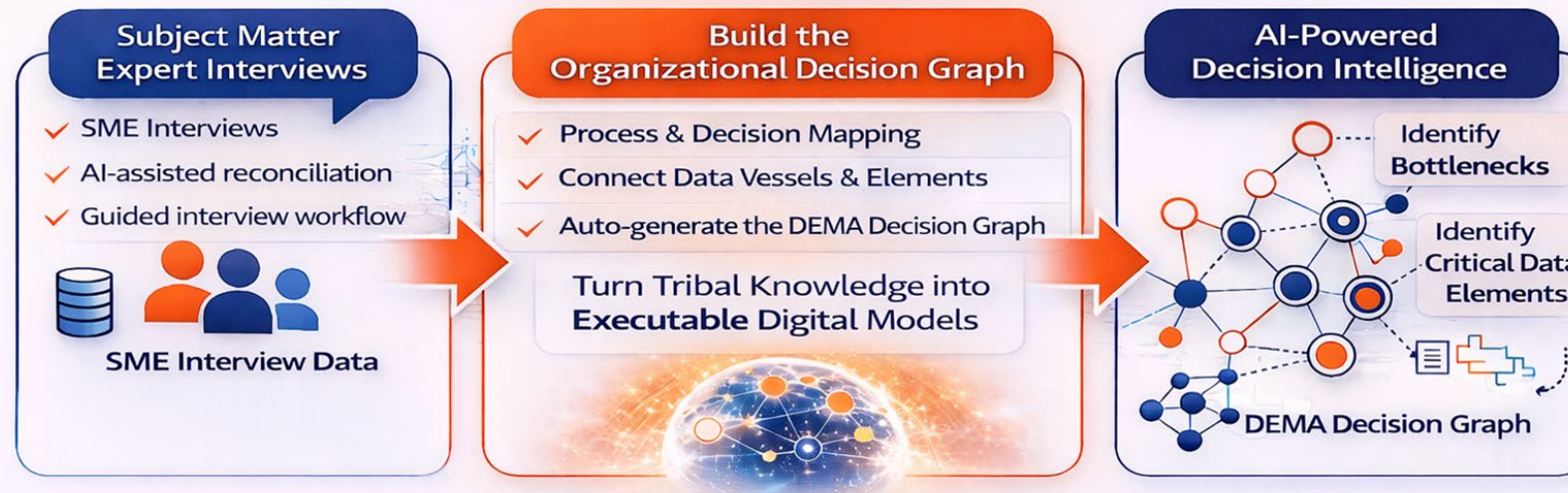


DEMA DECISION INTELLIGENCE PLATFORM

DEMA maps decision-critical data & dependencies

Transform SME knowledge into AI-ready enterprise models

DEMA – Decision Data Intelligence Platform



Applications Powered by the DEMA Decision Graph



DEMA enables ✓ Faster process improvement ✓ AI-ready enterprise knowledge ✓ Reduced decision latency

DEMA DECISION INTELLIGENCE PLATFORM

Current State

- ❖ DEMA software
 - ❖ Walks user through DEMA interviews and automates the mappings.
 - ❖ Calculates CIM4DE metrics.
 - ❖ Single user desktop application.
- ❖ Cameo Plugin for DEMA SysML Models (MBSE)
- ❖ DEMA results can be exported from software and inputted into any Gen AI to establish LORE.

Short Term (2027)

- ❖ Final DEMA software
 - ❖ Walks user through DEMA interviews and automates the mappings.
 - ❖ Calculates CIM4DE metrics.
 - ❖ Multi-user desktop application.
 - ❖ DEMA LLM reconciliation tool across interview results.
 - ❖ AI generated reports for recommended process improvement plans.
- ❖ Users can import data from Guided DEMA interview session.
- ❖ Complete Cameo Plugin for DEMA SysML Models (MBSE)
- ❖ DEMA results can be exported from software and inputted into any Gen AI to establish LORE.

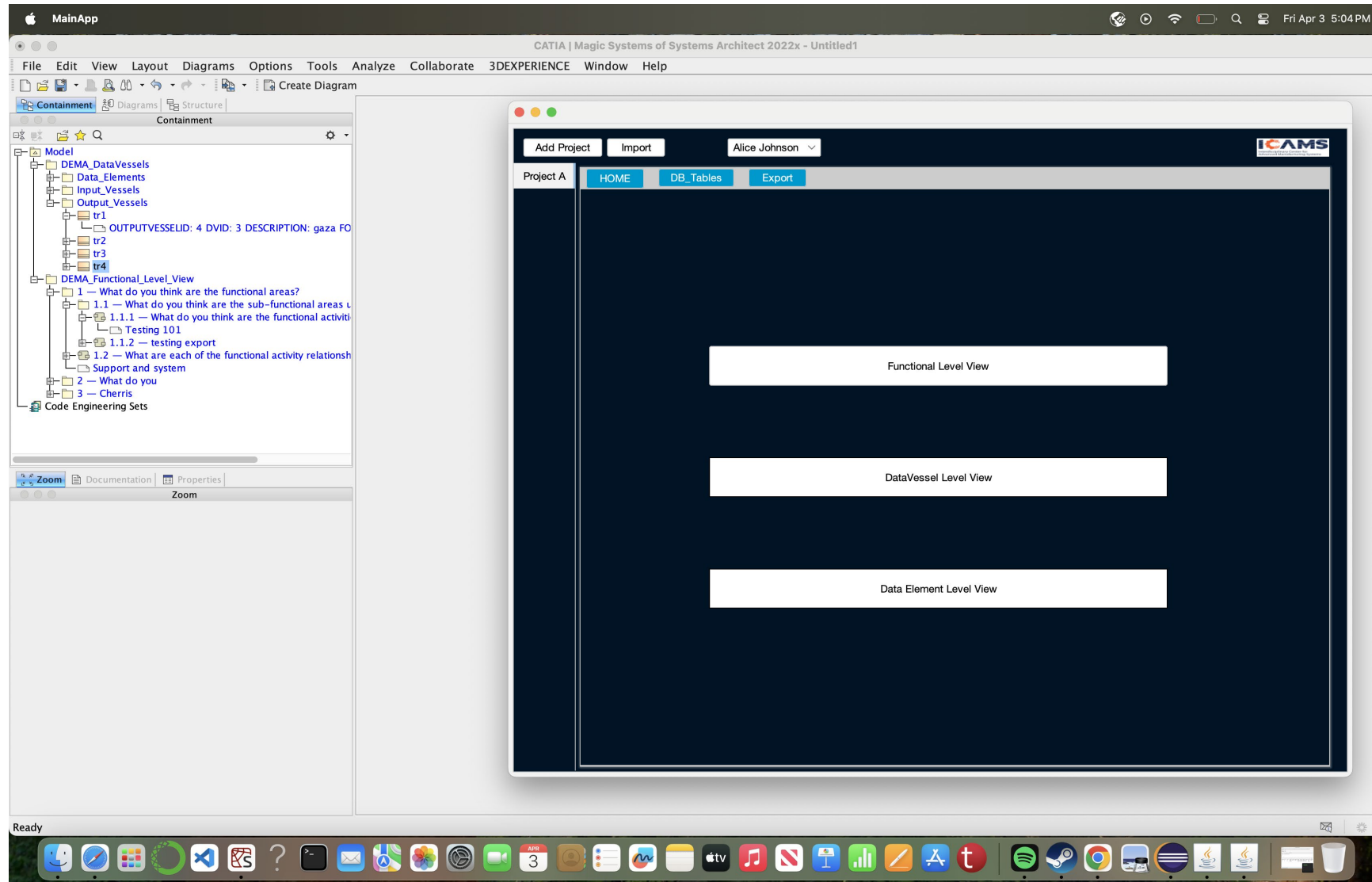
The Vision

- ❖ DEMA Decision Intelligence Platform
 - ❖ Full capability of previous DEMA software with built in applications to enable Guided DEMA, LORE, Digital Twin creation, and the export of executable models.
- ❖ Customized for different industries:
 - ❖ Defense and government
 - ❖ Healthcare
 - ❖ Small-and-medium sized manufacturers
 - ❖ Sales
 - ❖ Others

Auburn University (w/ federal funding)

Private Partners + Auburn University

DEMA WITH SYSML-BASED ARTIFACTS



LORE (LEARNED OPERATIONAL REFERENCE ENVIRONMENT)

ChatGPT ▾

Highest ROI Opportunity

If I had to give you ONE directive:

Improve how requirements and CAD data are structured and transferred

This will:

- Reduce downstream errors
- Reduce bottlenecks
- Improve overall system flow

If You Want to Go Further

I can now:

-  Show manual handling specifically on bottleneck nodes
-  Identify manual + high betweenness (highest ROI fixes)
-  Highlight these directly on your graph

Just say:

👉 *"combine manual + bottlenecks"*

👉 *"show automation opportunities"*

...and I'll take you to the next level 🔥 <code>

     ...



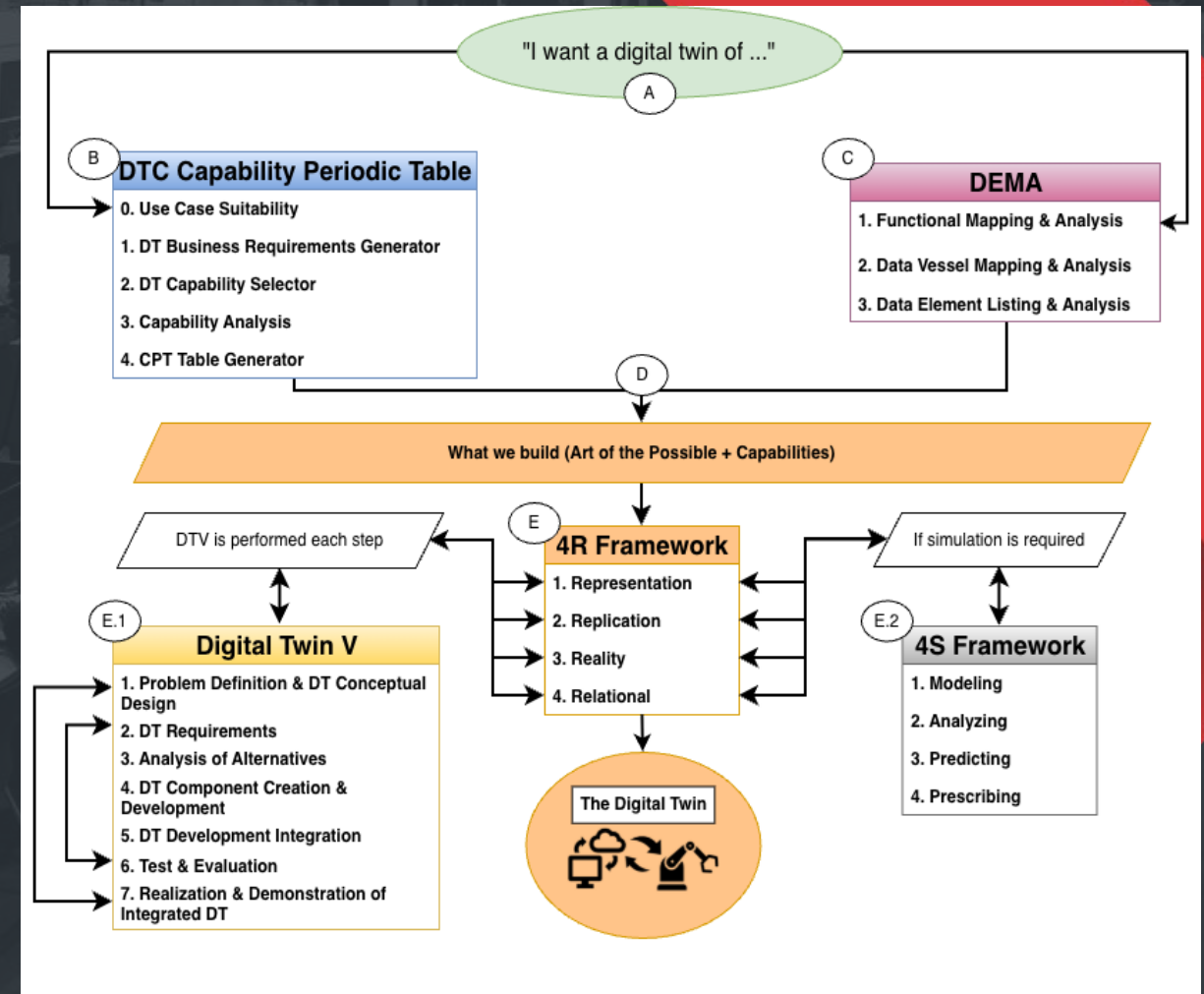
+ Ask anything





DTAF: Digital Twin Analytical Framework

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THE PROBLEM: DISCONNECTED MANUFACTURING DATA SILOS



Impact: When a part fails inspection, engineers cannot trace which design feature was affected, which process operations produced it, or which machine conditions caused the deviation — without manually digging through three separate data systems.

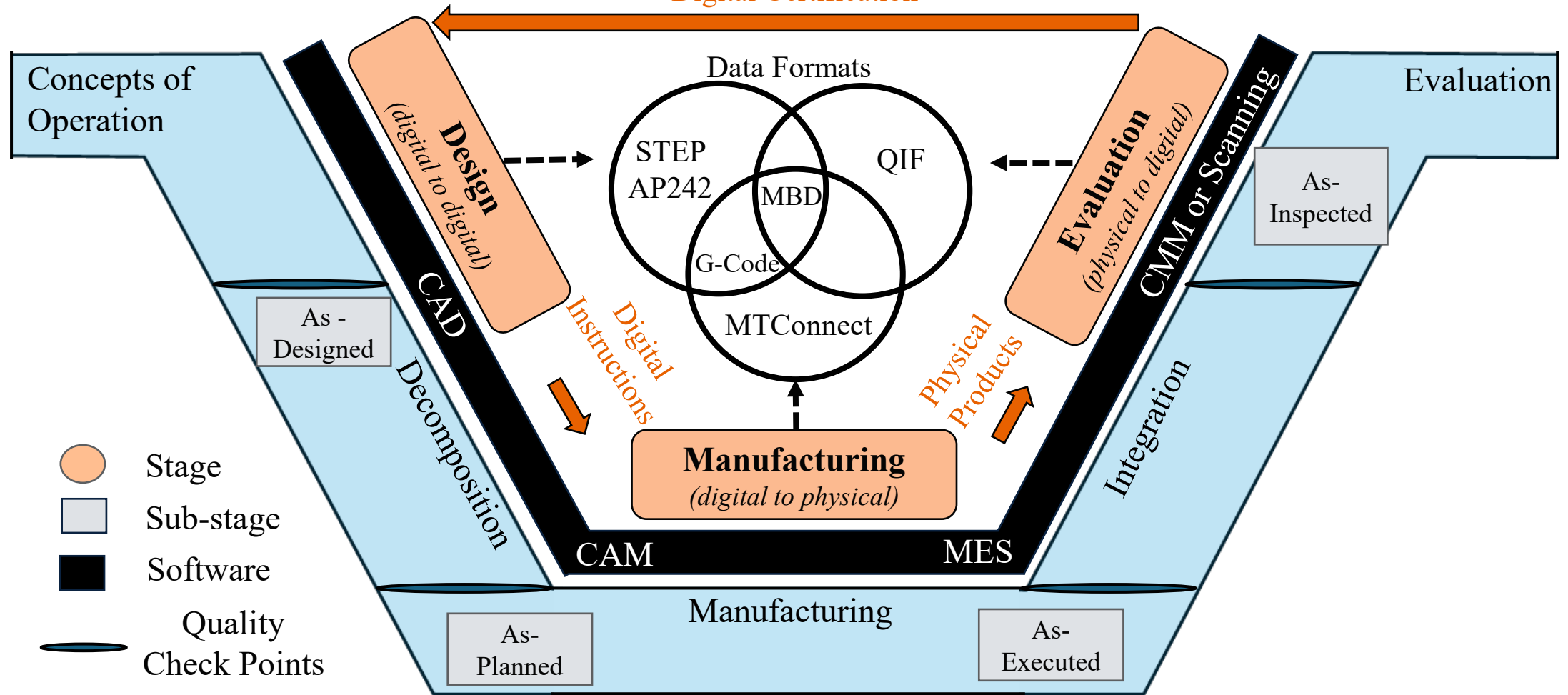
Goals:

- Integrate and Map MBD Product Characteristics with Operational Characteristics Data Elements
- Perform Root-Cause Analysis of Defects Related to Manufacturing and Inspection Operations

APPROACH TO ENHANCING THE MODEL-BASED DEFINITION

Process and Product Development Cycle

Digital Certification



UUID V5 — DETERMINISTIC IDENTITY SCHEME

Key property: UUID v5 uses Secure Hashing Algorithm for namespace + seed string. The same namespace–seed combination always yields the same UUID rather than generating random UUIDs

Any node can be independently reconstructed and verified without querying a central registry. This is essential for a reproducible, open-source digital thread.

1. Input String:

A variable string that uniquely represents the entity within your application.

- Do **not** use time-based values
- Use a **human-readable pattern**
- Include **location, feature identifiers, and operation context** to improve differentiation

2. Namespace:

A fixed UUID is combined with the input string to ensure uniqueness and distinguish UUIDs generated across different applications, systems, or domains.

DESIGN

Seed: PLATE::GEOM::boss_contour::dia4.000::cx35.457::cz64.160

UUID: 9f5c3d7a-2b8e-5f1a-c8a3-f72b4e9d1c30

Plan

Seed: PLATE::OP::OP1::T03

UUID: 27ff14b1-8e3c-5d9a-b4f2-a7c6e5d0f831

MFG

Seed: PLATE::MFG::Hurco04::RUN_17

UUID: c3d7e2f1-5a9b-4c8e-d6f0-b2a4e7c9d1f5

INSPECTION

Seed: PLATE::INSP::FAIR::Diameter5::SAMPLE_17

UUID: f1a8b3c5-4d7e-5f2a-b9c0-d3e6f7a8b1c4

EXPERIMENTAL SETUP – NIST DATASET [4]

STEP AP242

*File: *.step*

Format: ISO 10303 geometry

Parse: regex on CYLINDRICAL_SURFACE +

Data Elements: XY position, depth, diameter of every cylinder → design node

G-code / NC

File: 827-9999-904, OP.NC*

Format: Hurco CNC dialect, G20 (inches)

Parse: Tool-change trigger: N### G91 G28 Z0 M06

Data Elements: Op name, tool number, block range, XY drill positions

MTConnect

File: Part-Hurco04-NNof20.txt

Format: Pipe-delimited: timestamp|id|value

Parse: Filter by Current_Tool, Spindle_Speed, Feed_Rate, Block_Number

Data Elements: Spindle RPM, feed rate, tool sequence, runtime per run

QIF / FAIR

*File: *_Results.qif*

Format: XML — ISO 23952

Parse: CharItem → CharNominal → CharDefinition → actual

Data Elements: Measured value, tolerance, pass/fail per feature per run

3

Parts

20

Runs

60

MTConnect Logs

4

Data Formats

7,522

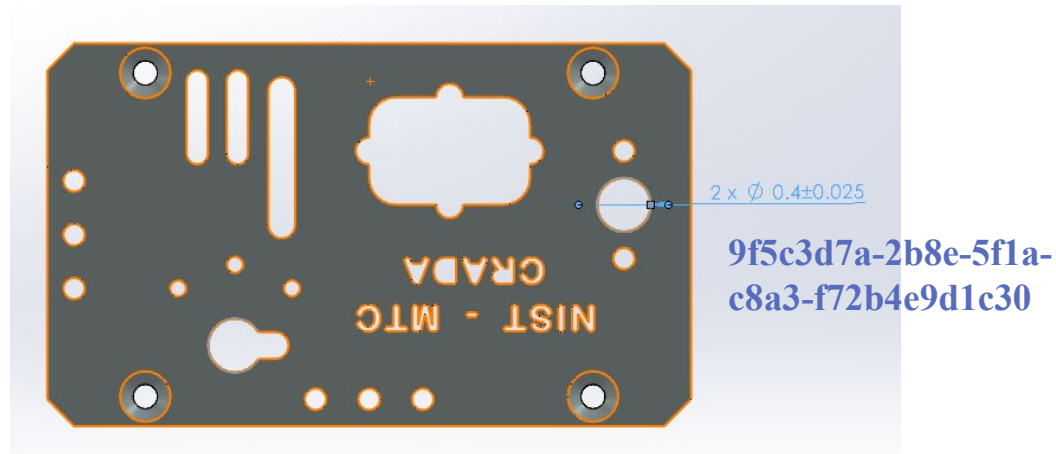
Thread Nodes

102

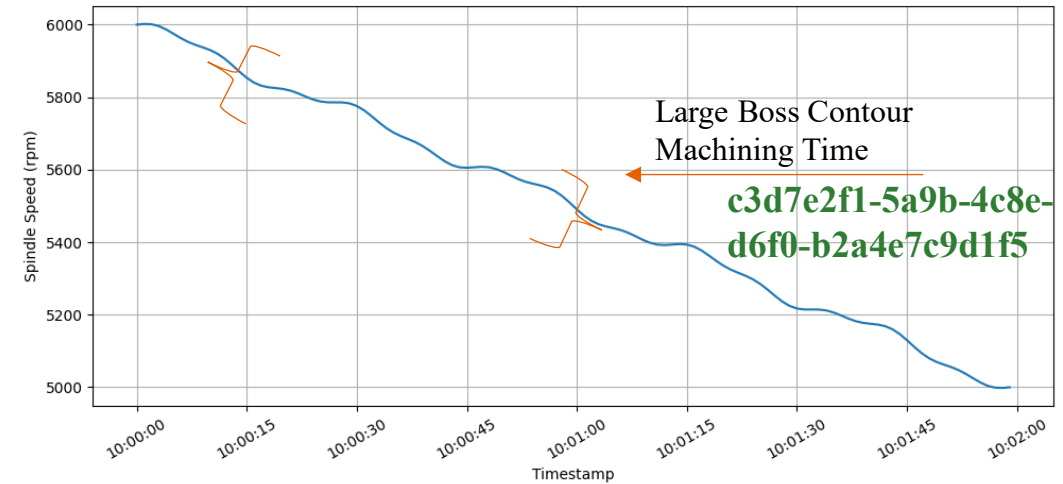
Total Failures

ASSIGNING UUIDS FOR DESIGN, MANUFACTURING, AND INSPECTION

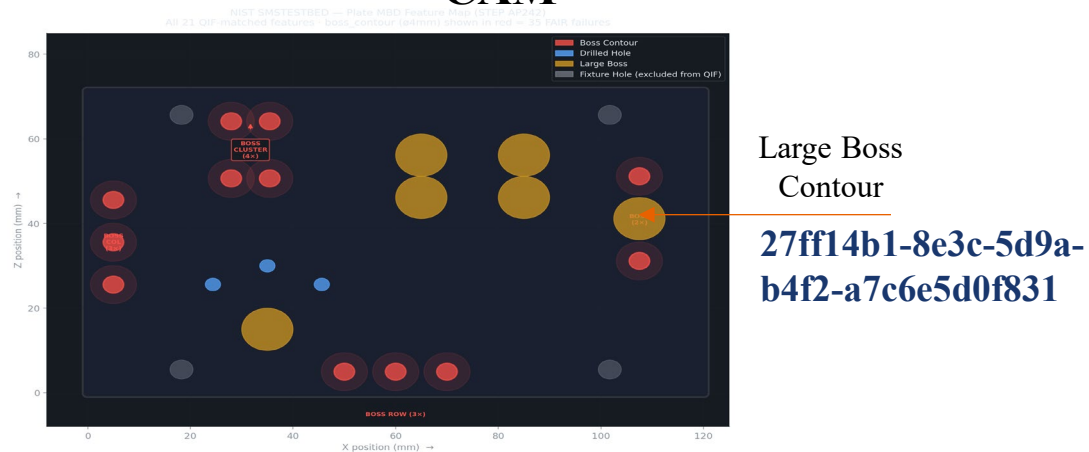
CAD



MES



CAM



CMM Measurements

QIF XML — Source File

7_31_2017 9:16:18 AM Plate_Results.qif

```
<?xml version="1.0" encoding="UTF-8"?>
<qifDocument>
  <measurementResults>
    <measurementResult>
      <!-- Feature Identification -->
      <featureName>
        Diameter 8
      </featureName>
      <!-- Characteristic type -->
      <characteristicActual>
        xsi:type="DiameterCharacteristic"
      </characteristicActual>
      <!-- Nominal & Tolerance -->
      <nominal>4.800</nominal>
      <upperTolerance>0.250</upperTolerance>
      <lowerTolerance>-0.250</lowerTolerance>
      <!-- Measurement result -->
      <measuredValue>3.995</measuredValue>
      <status>PASS</status>
      <sampleNumber>1</sampleNumber>
    </measurementResult>
  </measurementResults>
</qifDocument>
```

Parsed Fields → thread_inspection_layer.csv

Each row = one QIF characteristic measurement

Field	Value
uuid	5e6c5d65-7b2d-5961-b56c... -155404ffab00
uuid_seed	PLATE::INSP::FAIR::Diam...
part	Plate
insp_type	FAIR
feature_name	Diameter 8
char_type	Diameter
nominal	4.800 mm
upper_limit	4.250 mm
lower_limit	3.750 mm
measured_value	3.995 mm
status	PASS
sample	1

5e6c5d65-7b2d-5961-b56c...
-155404ffab00

PLATE::INSP::FAIR::Diam...
eter 8::SAMPLE_01

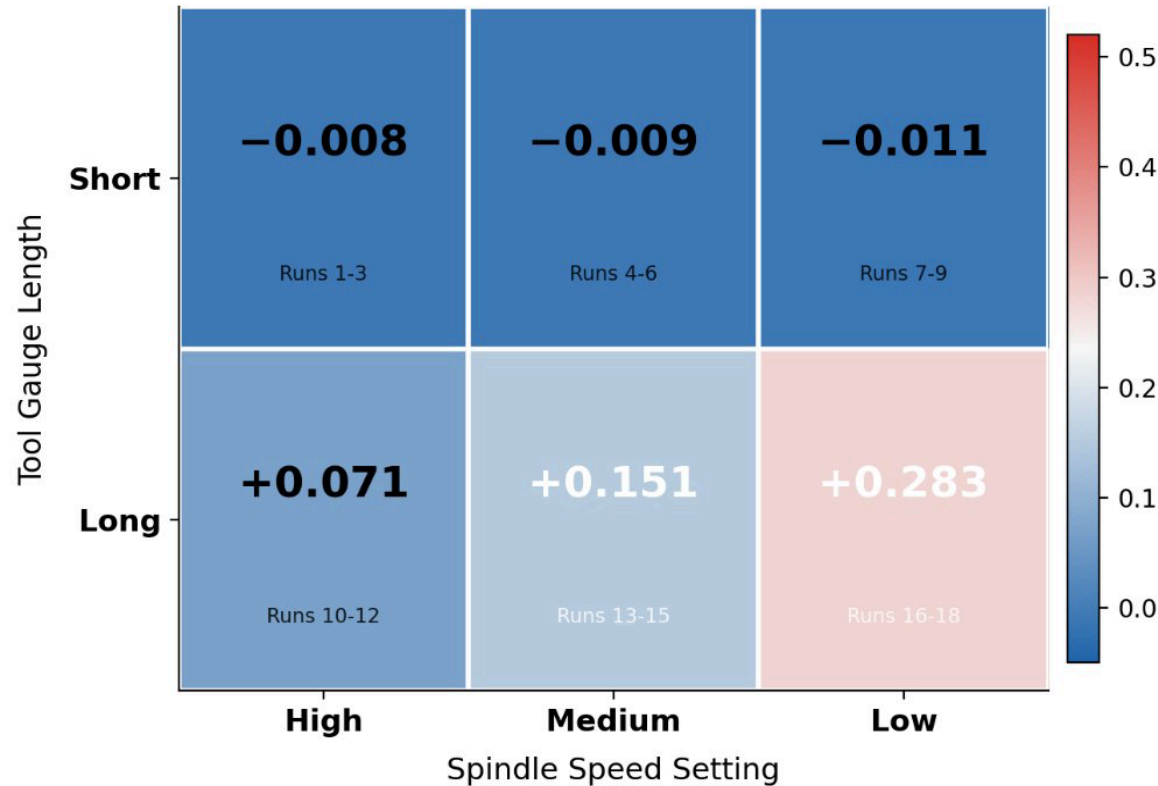
3.995 mm

DIGITAL ENGINEERING METRICS [5]

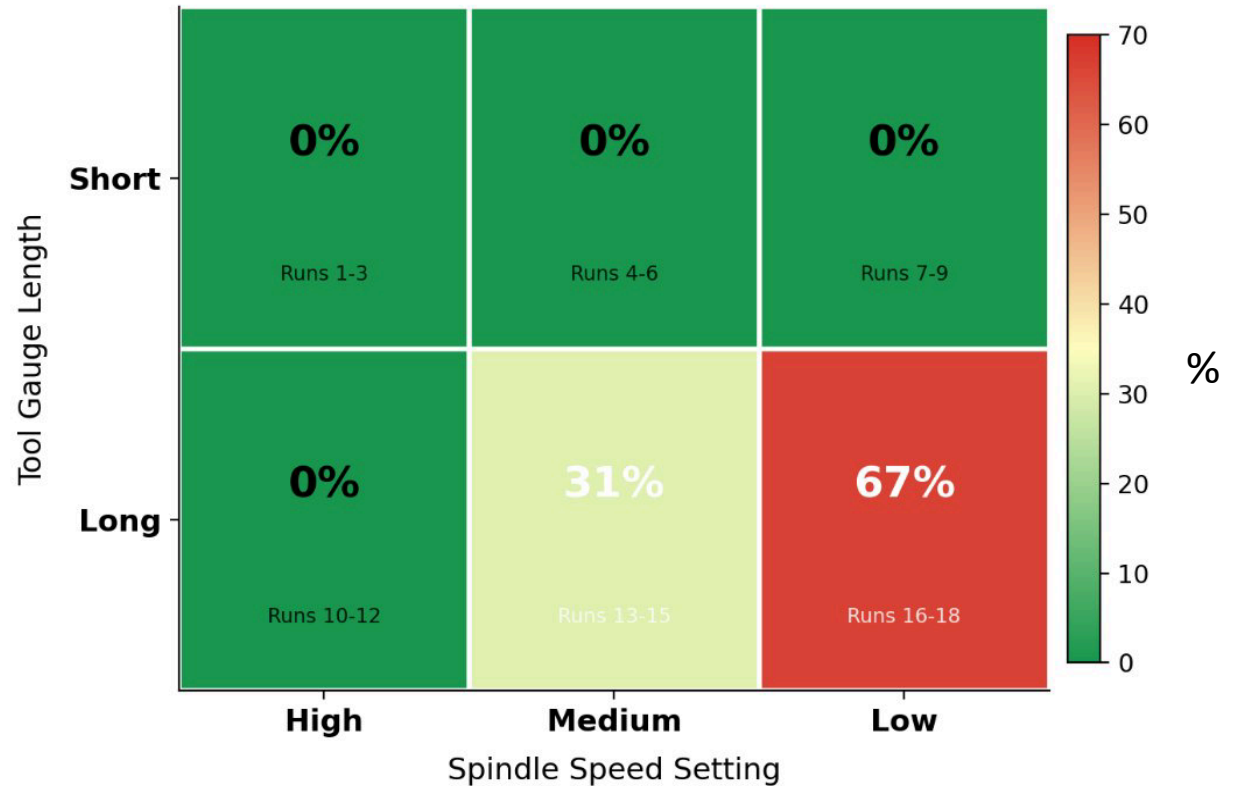
Category	Metric	Evidence / Outcome
Quality	System quality	3,021 UUID-linked inspection records , enabling full traceability of failures to specific runs and STEP-defined features
	Defects	Cone Angle 3 FAIR FAIL: 88.953° vs nominal 90.0°, traced via UUID to G-code deviation of –25.3% in Run 01
Velocity / Agility	Time	MTConnect runtime captured for each run; avg. 2,380 s/run with 16.4 tool changes
	Rework	374 significant deviations identified across 60 runs, indicating elevated rework risk
	Ease of making changes	UUID v5 enables automatic relinking of data following design or process changes
User Experience	System understanding	Four linked lifecycle views: Design, Process, Manufacturing, and Inspection
	Effort	27,894 traceability links generated automatically with no manual curation
Knowledge Transfer	Accessibility of information	All 84 design features accessible across the other three lifecycle domains via UUID-based linkage
Adoption	Project methods / processes	Industry Standard Enabled Digital Thread: STEP → G-code → MTConnect → QIF , demonstrated across 3 parts × 20 runs = 60 end-to-end threads

PLATE 4MM BOSS CONTOUR – 3X3 FACTORIAL DESIGN

Mean Diameter Deviation (mm)
from 4.000mm nominal



% Measurements FAIL
(FAIR inspection, ø4mm features)



0%

*Short tool fail rate
(all 9 speed/feed combos)*

67%

*Long+Low speed fail rate
(Runs 16-18)*

+0.48mm

*Long+Low mean deviation
from 4.000mm nominal
tolerance*

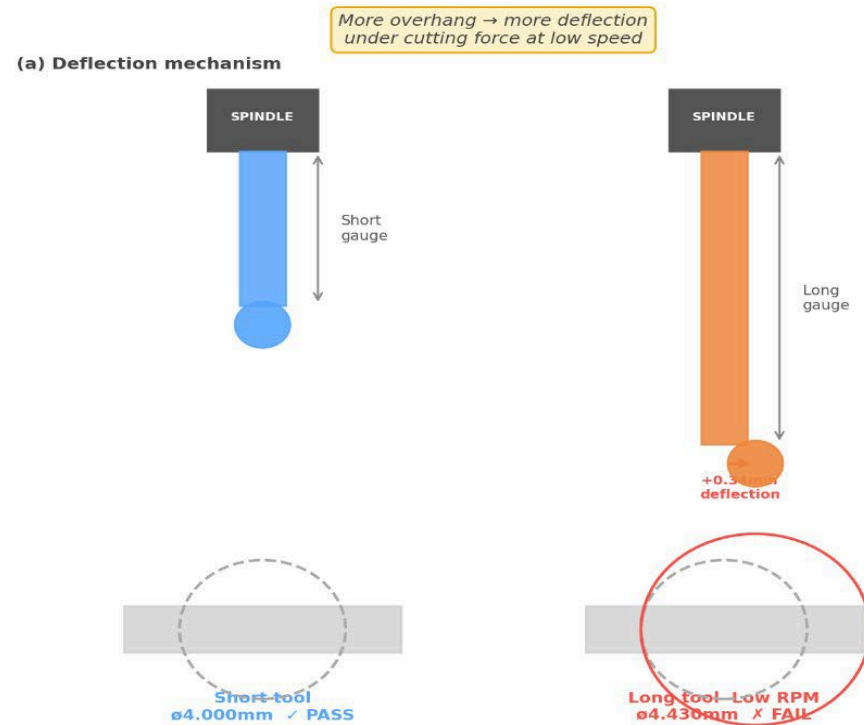
+0.27mm

*Short tool mean deviation
(within tolerance)*

CNC MACHINING ISSUE – TOOL DEFLECTION

Long gauge length + low spindle speed → outward radial deflection during contour pass

Failure Mode 1 – Tool Deflection: Mechanism and Evidence

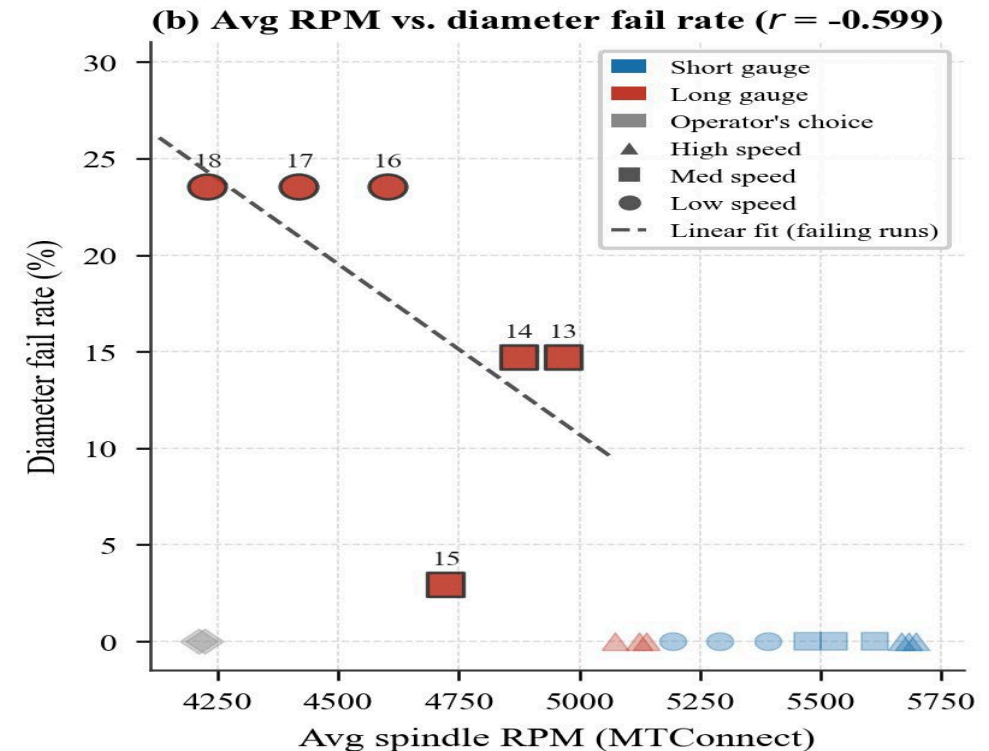
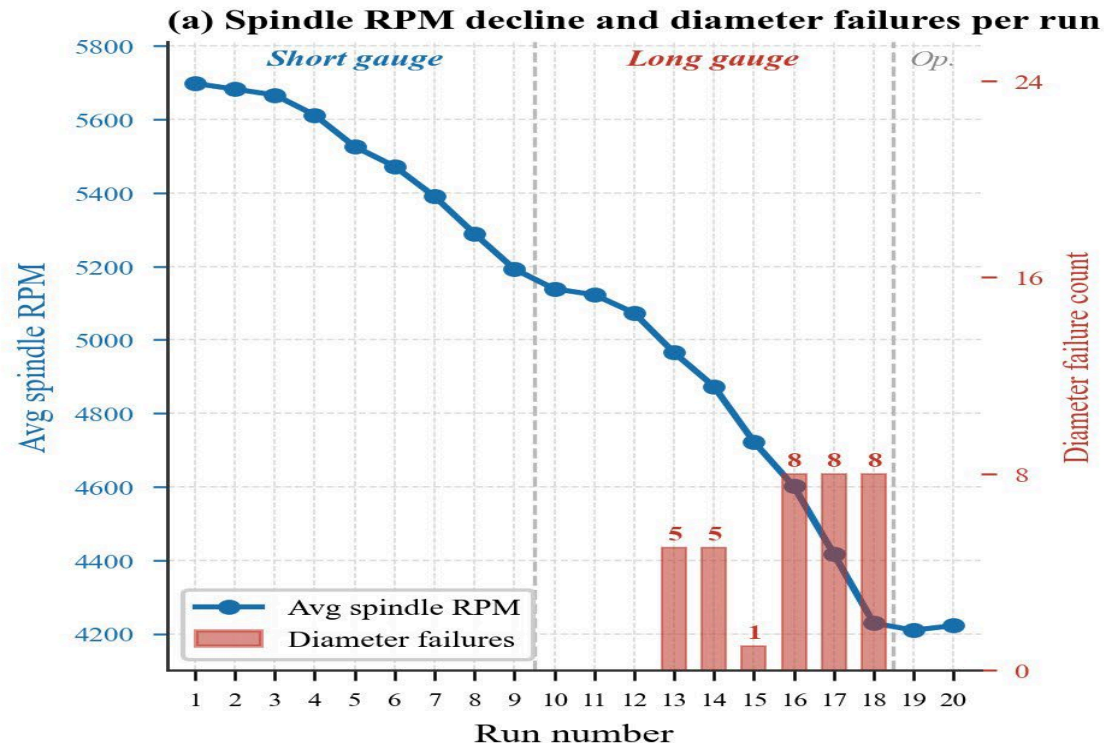


Root Cause: Long gauge length increases tool overhang, amplifying deflection under radial cutting force. At low spindle speeds, reduced centrifugal stiffness causes deviation

- The endmill deflects outward during the boss_contour finish pass, leaving the bore oversize. Short tool or high speed → stiffness sufficient → no deflection.

CNC MACHINING ISSUE – TOOL DEGRADATION

Plate ø4mm boss_contour — spindle RPM and diameter failure rate
Cone angle systematic failures excluded · FAIR inspection



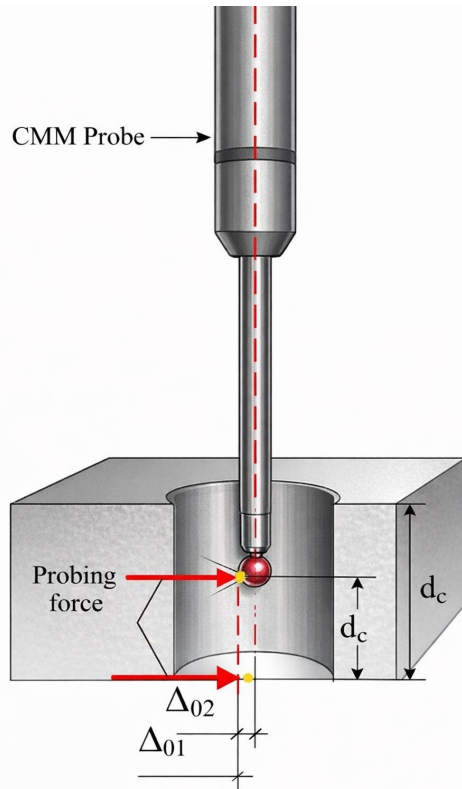
RPM explains ~36% of variance: meaningful signal but not the complete story

Critical threshold ~4,577 RPM: failures spike below this level — identified as the danger zone

Implication: programmed speed is an unreliable predictor — actual measured RPM from MTConnect is required for accurate failure prediction.

CMM SETUP ISSUES – TOOL DEFLECTION

Distinct from tool deflection: fixture or CMM setup issue, not a cutting parameter effect



63

*Cone angle FAIL
measurements*

88.92°

*Mean measured
(nominal 90°)*

−1.08°

*Systematic bias
(all 20 runs)*

0.11°

*Std deviation
(very consistent)*

Key Characteristics of Failure Mode:

- Present in ALL 20 runs regardless of tool length, spindle speed, or feed rate
- Consistent -1.08° bias with very low variance ($\sigma = 0.11^\circ$) — indicates a systematic offset, not random variation
- All 4 cone angles on the Plate show the same deviation simultaneously
- Not correlated with any cutting parameter in the experimental design
- Diagnosis: fixture misalignment or CMM datum setup error — measurement artefact, NOT a machining defect

vs Failure Mode 1 (Diameter):

- Tool deflection → correlated with Long+Low speed → fixable by changing cutting parameters or tool holder length.
- Cone angle bias → systematic offset → fixable by CMM/fixture recalibration only.



SUMMARY

DEMA

- DEMA software enables streamlined stakeholder Q&A workflows to support AI-driven decision-making and estimate ROI using CIM4DE metrics.
- Automates process model generation in SysML to accelerate completion of required models and support compliance with DoD digital engineering mandates.

MBD

- Provides a methodology for achieving a higher level of integration across design, manufacturing, and metrology domains.
- The approach is grounded in industry standards, enabling systematic and scalable integration.
- Enable root cause analysis to identify errors originating from both the manufacturing and inspection processes.

FUTURE WORK: UPSKILLING MANUFACTURING WORKFORCE IN DIGITAL THREAD

1. Application Scenarios and Data Workflows Demonstrations

Develop use-cases and demonstrations to showcase value-added digital thread for timelier and efficient delivery of new and traditional manufacturing systems

2. Data Element Mapping Integration with Process Automation Capabilities

Develop tools that automatically support digital thread implementation and help manufacturers address gaps in their current data practices.

3. Process Intelligence Platform for Role-Specific Information Delivery

Provide contextually relevant operational instructions and visuals to manufacturers stemming from the available data element mapping and analysis



Interdisciplinary Center for
Advanced Manufacturing Systems

Survey of Top Challenges Facing Manufacturers (76% SMM) [6]

2023	Access to Capitol	Capital Improvements	Competitive Pressure	Operational Efficiency	Revenue/ Profits	Sales/ Marketing	Workforce- Engineering	Workforce- Operations
#1	9%	7%	8%	16%	10%	10%	10%	31%
#2	10%	8%	7%	18%	13%	8%	15%	23%
#3	6%	12%	9%	25%	12%	10%	16%	10%



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