
Connecting the Dots: Leveraging the Digital Thread for Enhanced Prototyping at MIT Lincoln Laboratory

Denise Fitzgerald

March 6, 2024



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Outline



- **Background**
- **How Did We Decide Digital Thread is the Answer?**
- **Examples of the Thread**



MIT Lincoln Laboratory

DoD Federally Funded Research and Development Center

Technology in Support of National Security

- Forward-looking national security architectures
- Long-term technology development
- Unique pathfinder prototypes
- Agile technology transfer





Trends Driving Lincoln Digital Engineering Effort

Complex Systems



- Coupled subsystem performance
- Mission driven prototypes
- Broad mission space
- Traceability

Aggressive Performance Targets



- High precision
- Coupled physics
- Engineered materials
- Virtual-Physical risk reduction

Faster Design Cycles



- Technology Transfer
- Efficient execution
- Reuse
- AI/ML opportunities



MIT Lincoln Laboratory

DoD Federally Funded Research and Development Center

Technology in Support of National Security

MIT Lincoln Laboratory researches and develops a broad array of advanced technologies to meet critical national security needs. What sets us apart from many national R&D laboratories is our focus on building operational prototypes of the unique systems we design.

Mission Areas

Advanced Technology	Air, Missile, and Maritime Defense Technology	Air Traffic Control	Biotechnology and Human Systems	Communication Systems	Cyber Security and Information Sciences
Engineering	Homeland Protection	ISR Systems and Technology	Space Systems and Technology	Tactical Systems	

Engineering

- Engineers / Designers / Technicians
- Design / Engineering / Analysis of Hardware
- Fabrication – PCB and Mechanical
- Assembly
- Test
- Scientists and Engineers
- Government sponsor relationship
- Development / Engineering of technology
- High level of analytical modeling
- Some prototyping

Annual Funding
\$1.4B

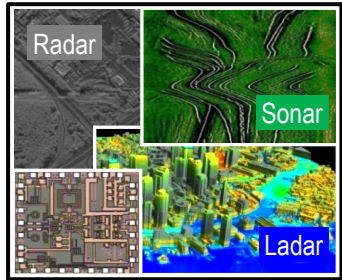
Number of Employees
~4,300



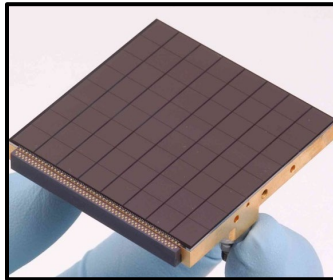
Range of Laboratory Programs

Advanced Technologies

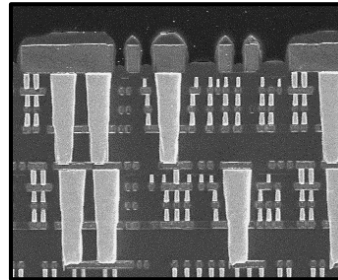
**Sensing Components
Signal Processing**



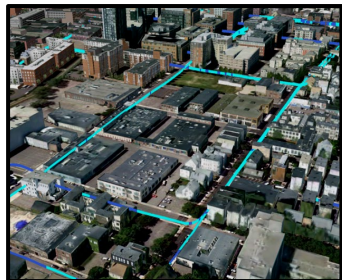
**Advanced
Imaging**



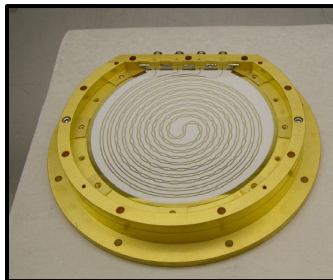
**Advanced
Silicon**



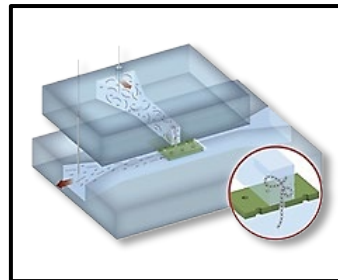
**Tactical
Networking**



RF Technology



**Molecular
Diagnostics**

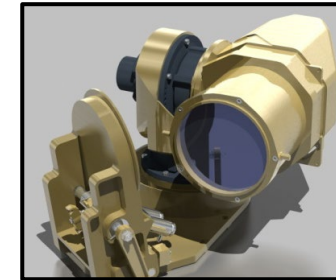


Advanced Prototypes

**Space Surveillance
Telescope**



**Lunar Laser
Communications Demo**



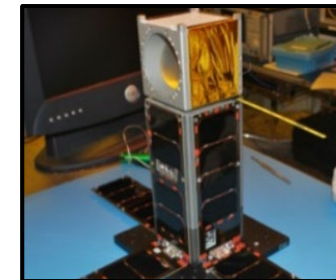
XTR-1 Radar



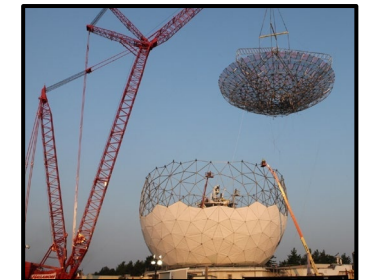
**Rapid Agent
Aerosol Detector**



**MicroMAS Weather
Sensing CubeSat**

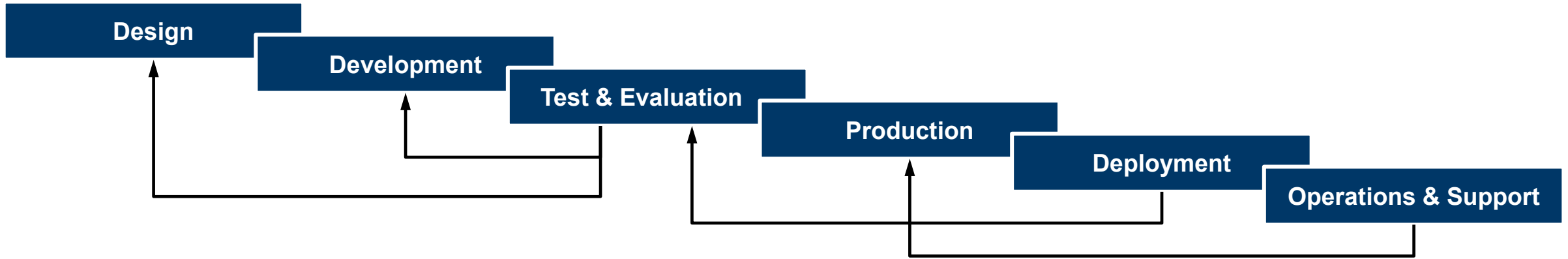


HUSIR W-Band





Digital Engineering Enabled Workflow



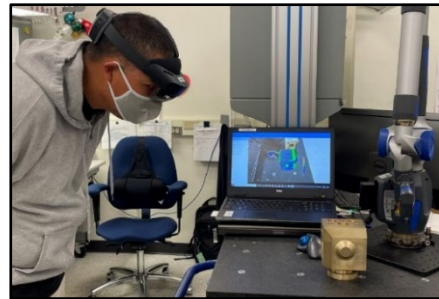
Conceptual Design and System-Level Trades



Complex Part Fabrication



Inspection and Capture



Field Test Data



Sustainment



Enterprise Connectivity

Customer & Partner Web-Portal Access

MBSE System Architecture

AR/VR-Enabled Process Development

Modern Tools

Data Access and Traceability

Continuous Review and Validation

End-to-End Data Aggregation

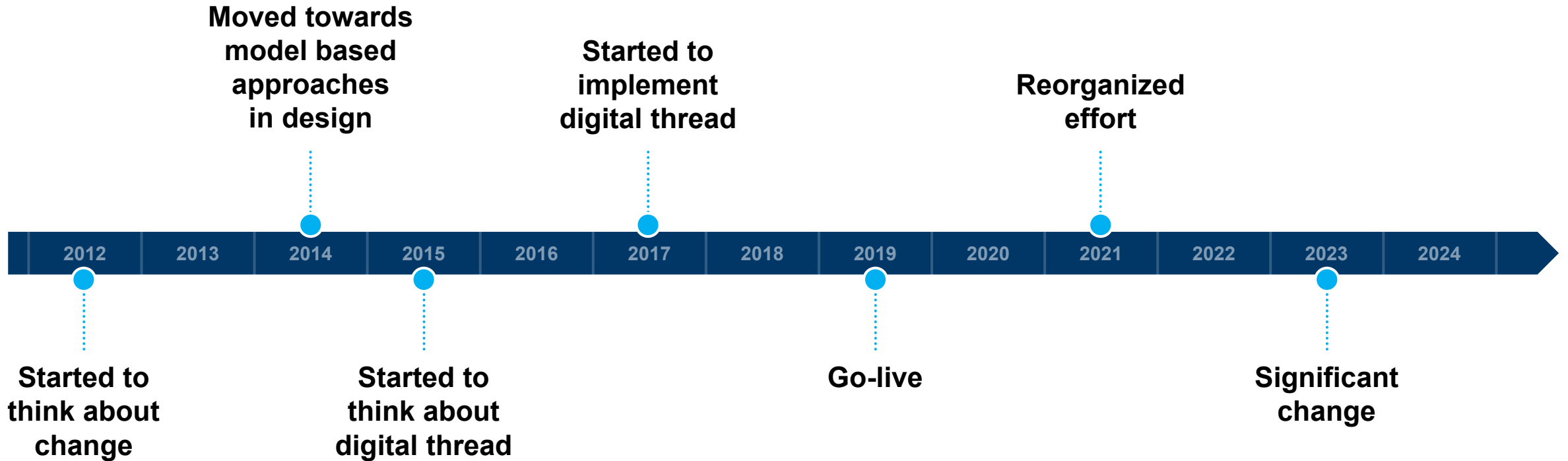
Knowledge Capture and Reuse

Operational Data Monitoring

...



Digital Transformation Timeline





Outline

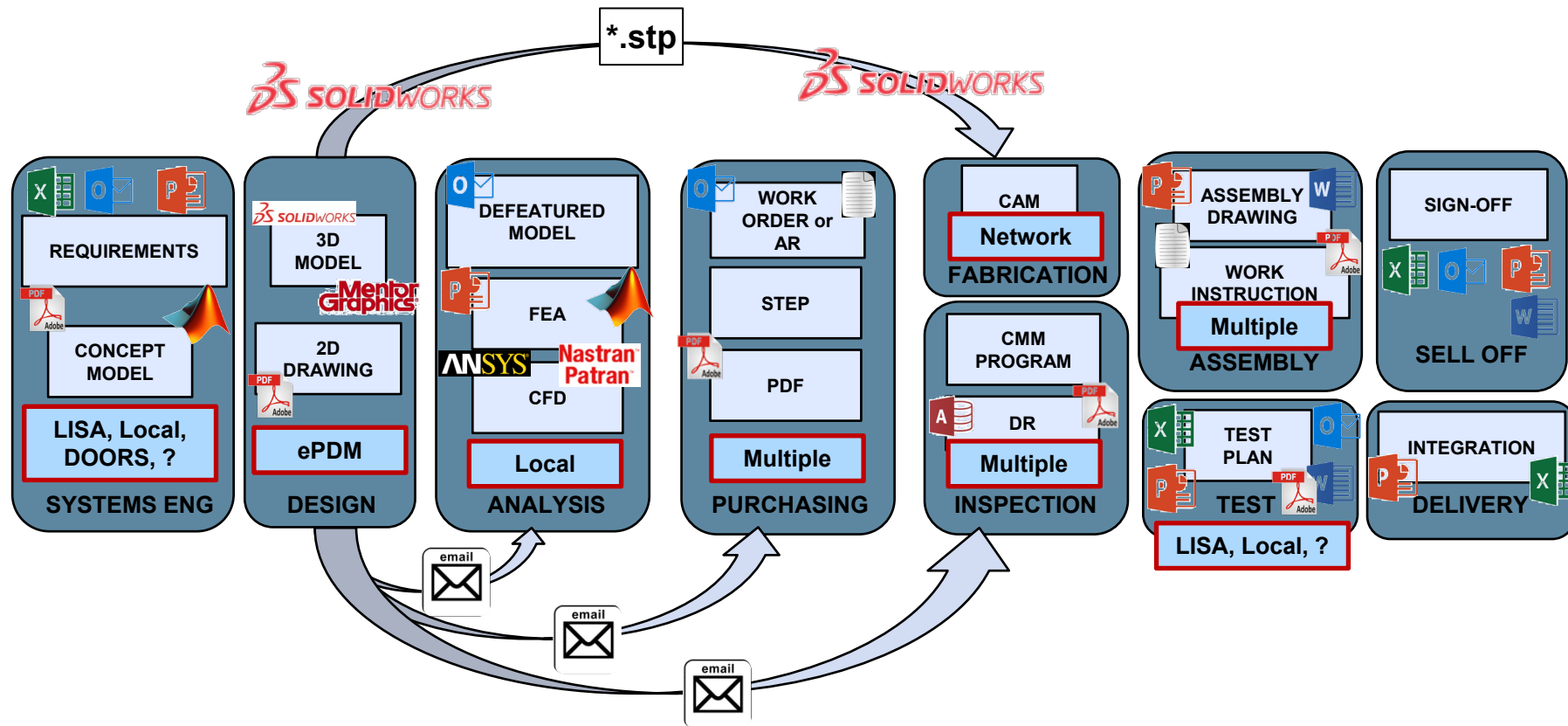
- Background
- ➔ • **How Did We Decide Digital Thread is the Answer?**
- Examples of the Thread



So, What Was the Problem?



2014 Lincoln Laboratory Engineering Systems



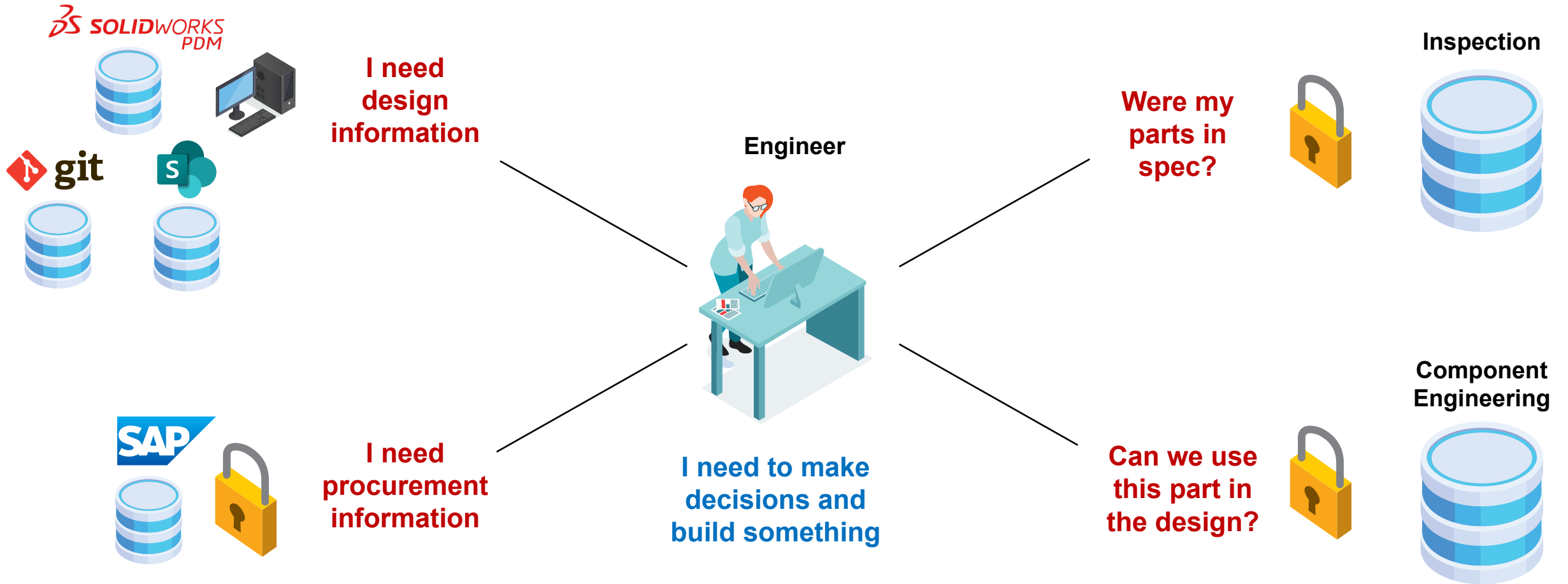
- Data resides in multiple places
 - Incompatible systems and paper processes
- Copying and re-creation of data is a source of error and inefficiency



**OK, There are A Lot of Systems.
What Was Really the Problem?**



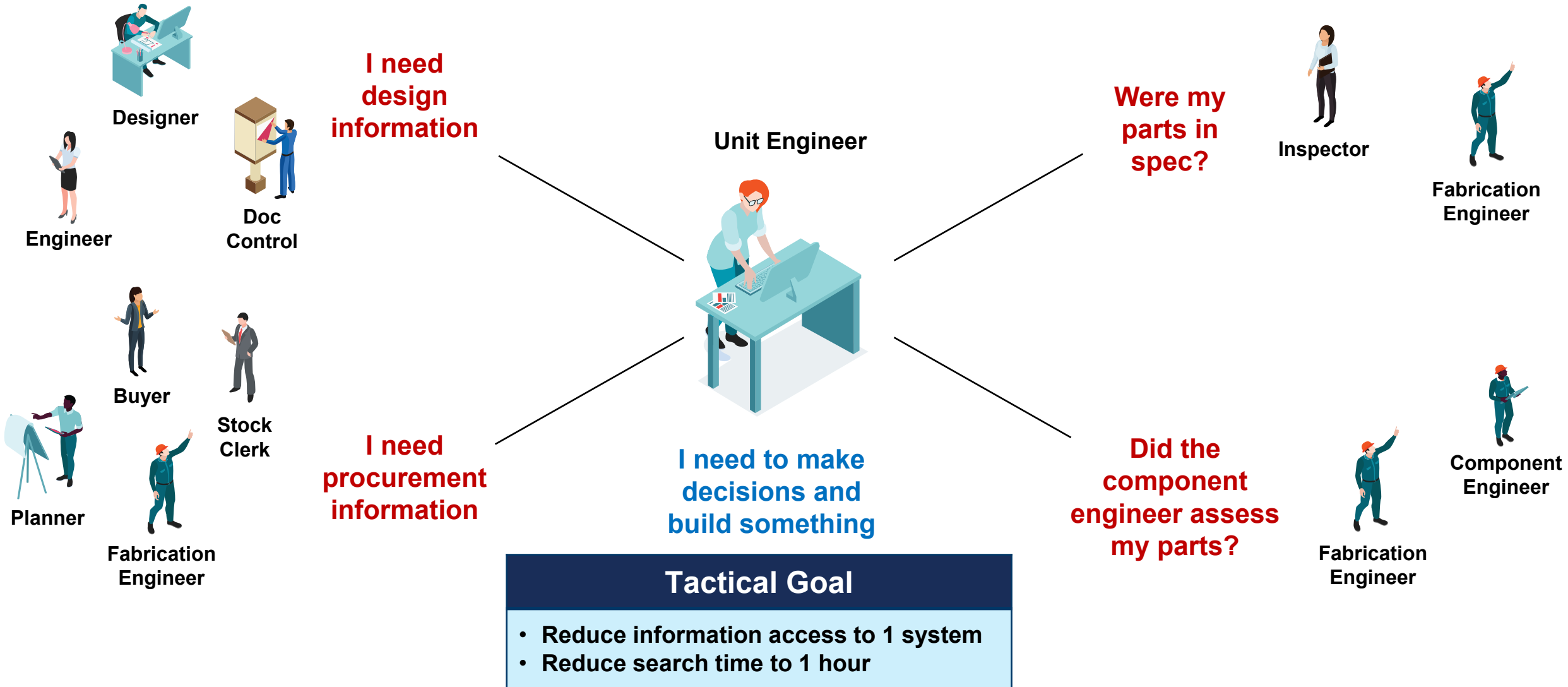
Access Challenges



Study showed that it took up to 3 days for staff to access information



Legacy Access Challenges





OK, People Need Access.

What Was Really the Problem?

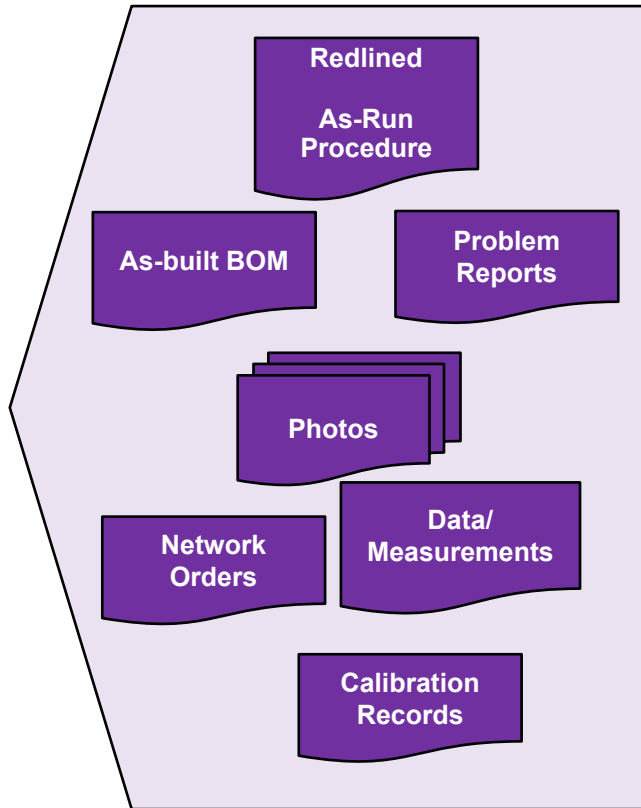
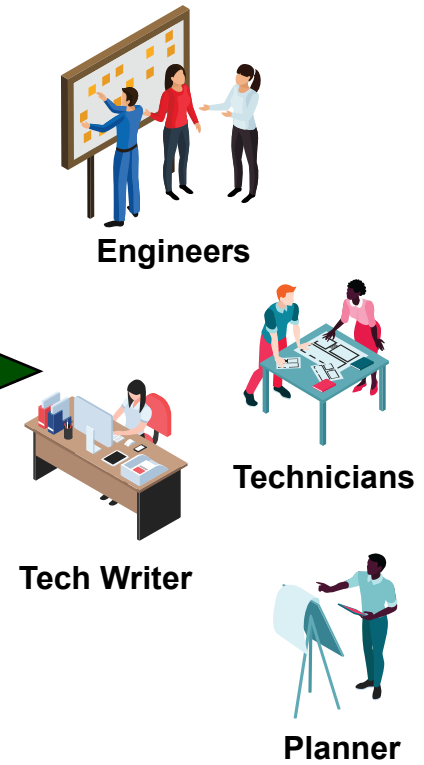
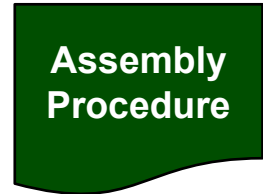
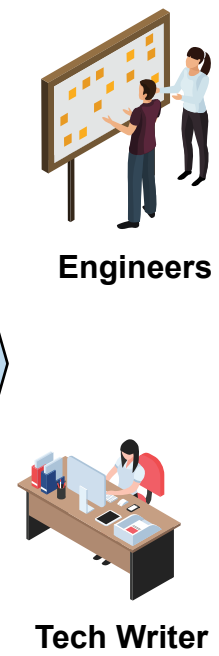
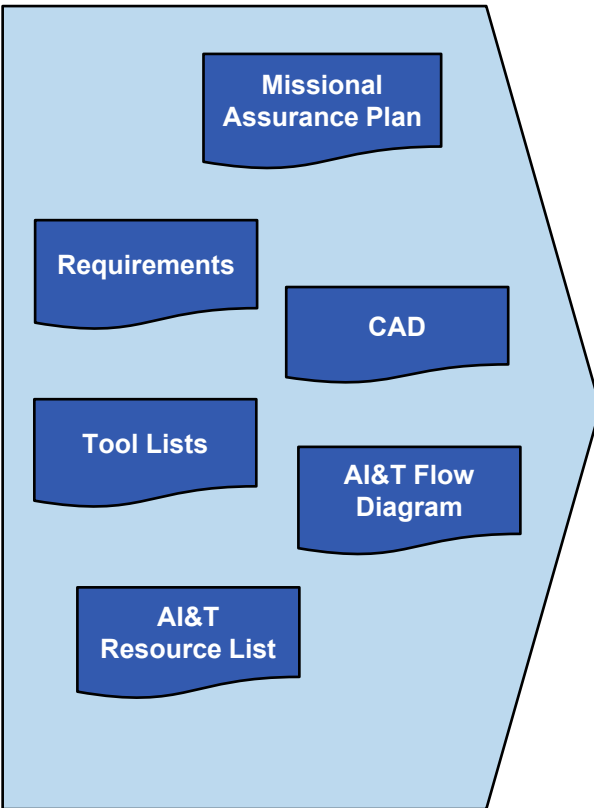


Current Process – AI&T

INPUT

Documents capture significant amount of related information

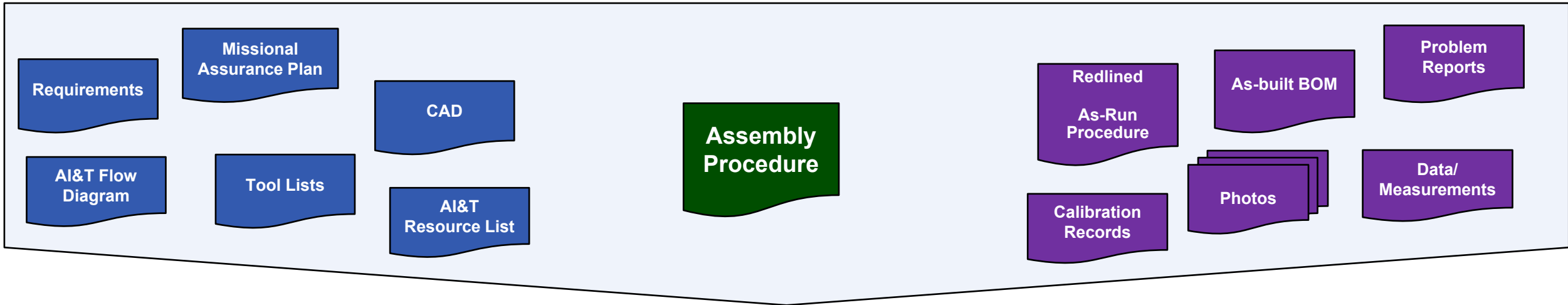
OUTPUT



Documents capture significant amount of related information



AI&T Related Tasks



Tech Writer

Update Procedures
Reconcile Changes



Systems Engineer

V&V
Data collection



Unit Engineer

Reconcile build
Understand change



Analyst

Find data
Validate design



MAO

Verify pedigree
Report

**All of these documents need to be interpreted to do work.
They were often inconsistent.**



So, what was really the problem?

We didn't see our work as being connected which caused:

- Silos of data**
- Delays in decision making**
- Significant recreation of data**
- Mistrust**



Digital Engineering Goals

Connect People

Engineer in a connected Digital Engineering Environment

Connect Data

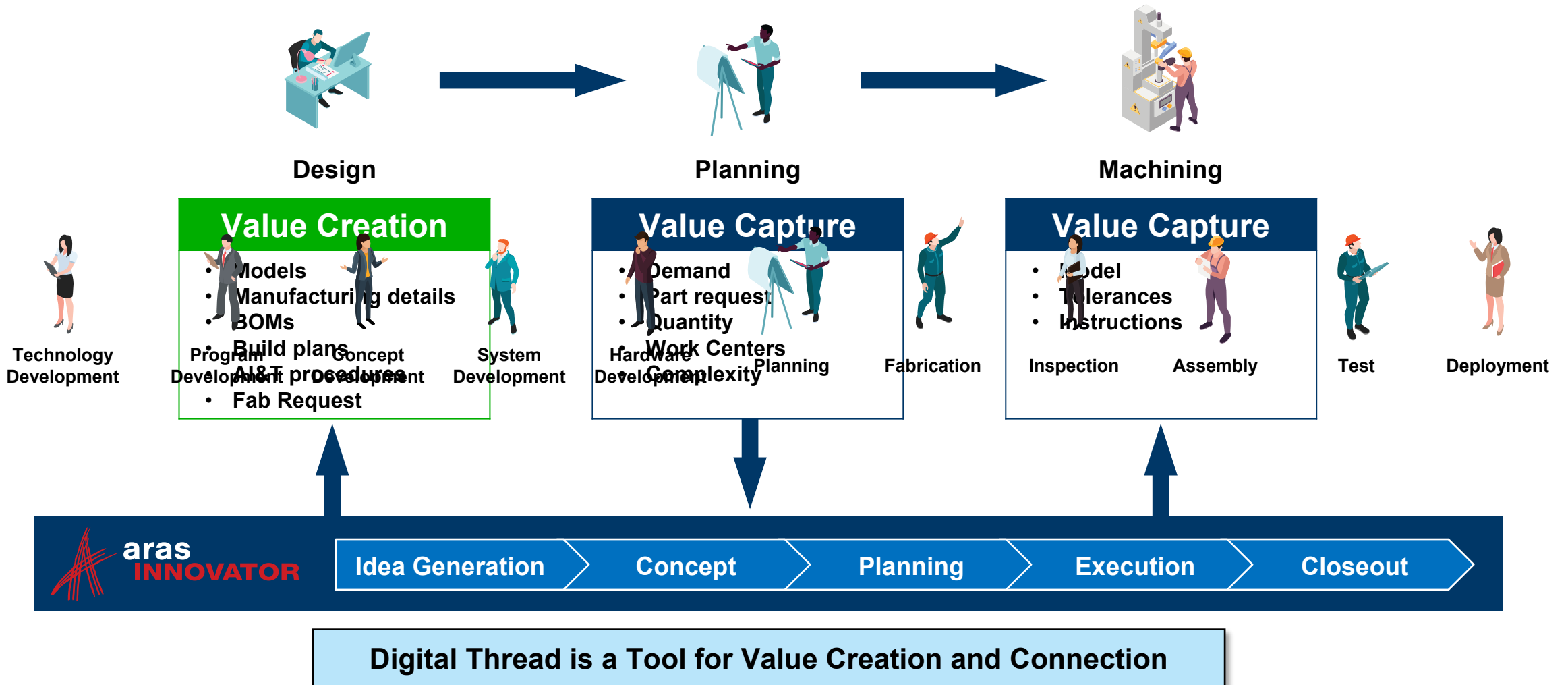
Provide common, controlled data in a digital thread

Informed Decision Making

Use modeling and simulation to define engineering and engineering activities

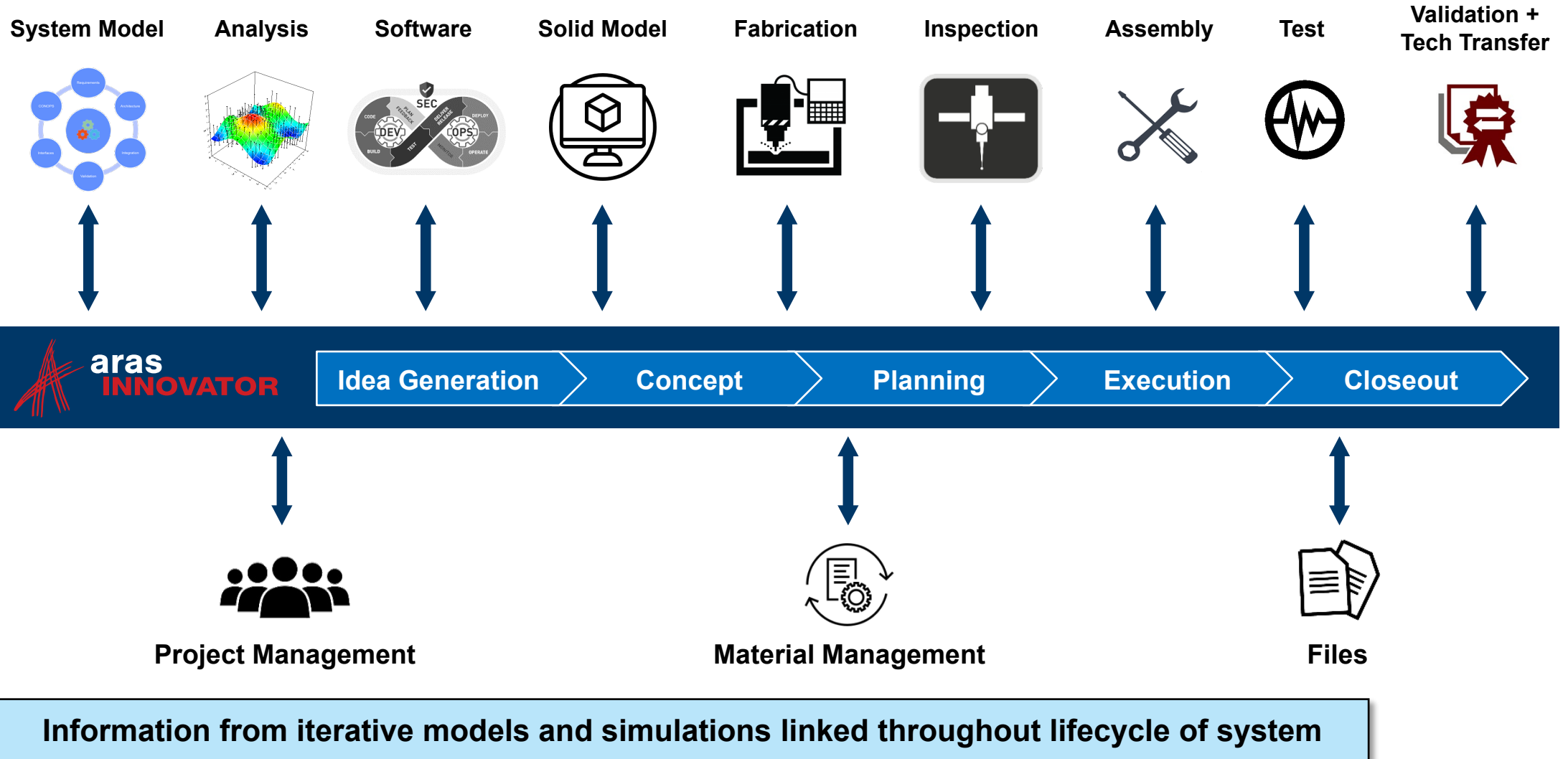


Value Streams





System Concept





Vision for Lincoln Digital Engineering

**Real-Time Data Access
and Configuration
Management**



**Collaborative Cross
Domain Modeling And
Simulation**



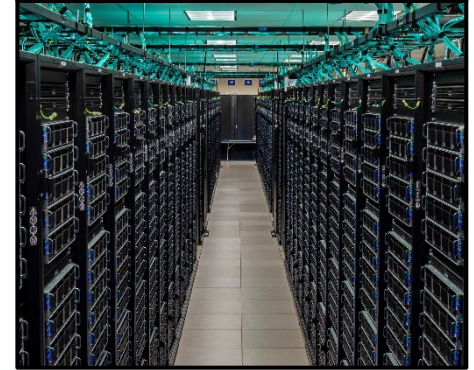
AI/ML Technologies



Visualization Tools



Super Computing



Integrated DE Platform

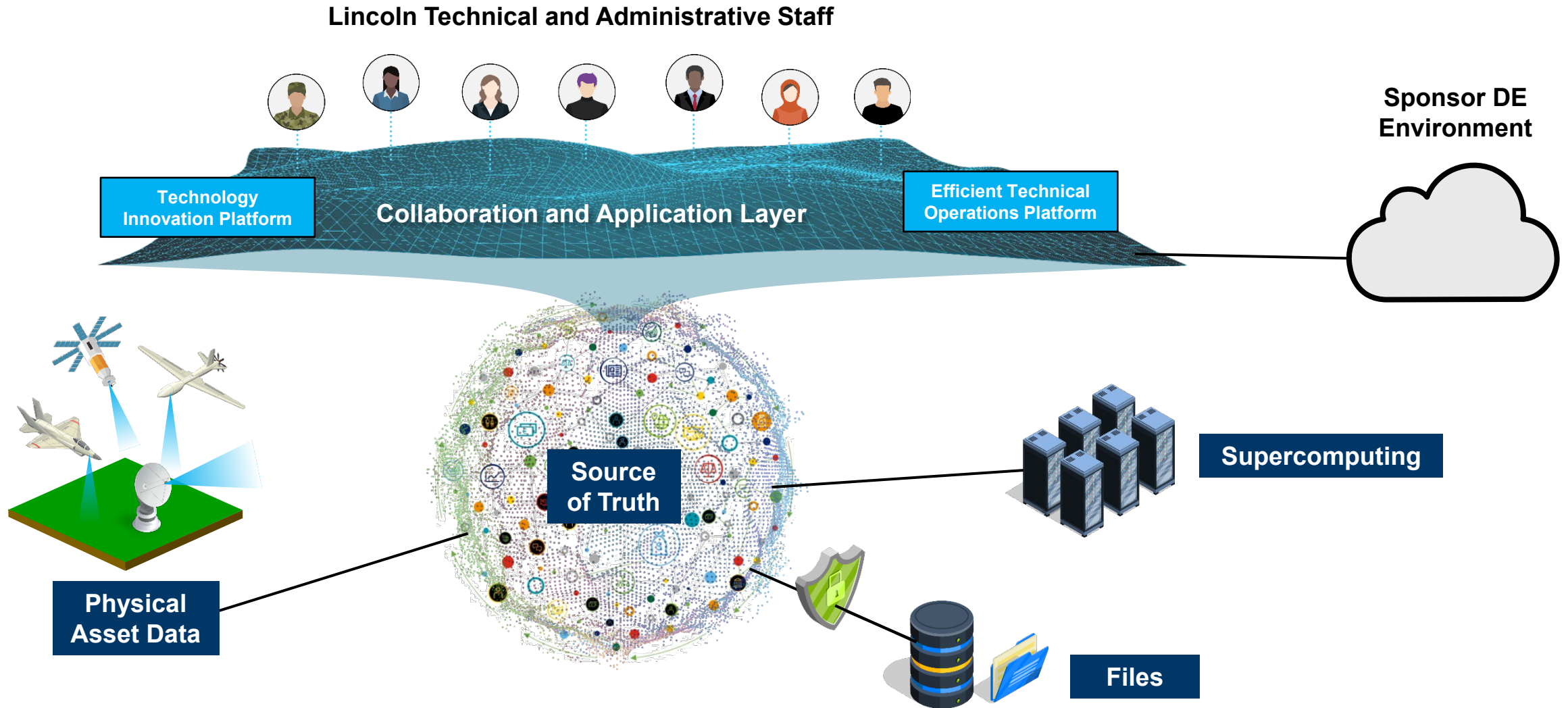
Data Driven Decision Making

Predictive Modeling

High Quality Prototypes, Dynamic Execution



Digital Engineering Environment Concept



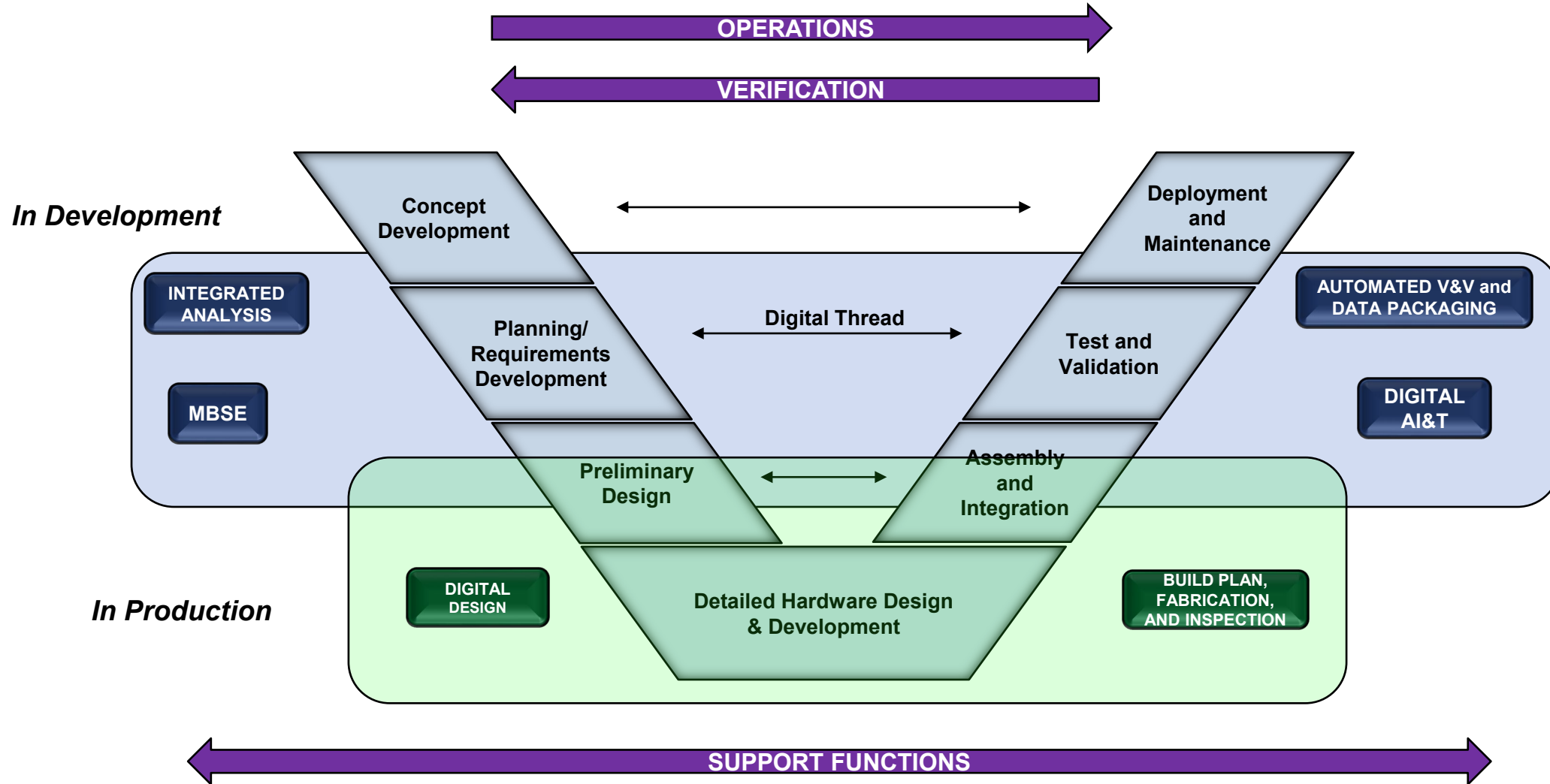


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- **Background**
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- ➔ • **Examples of the Thread**

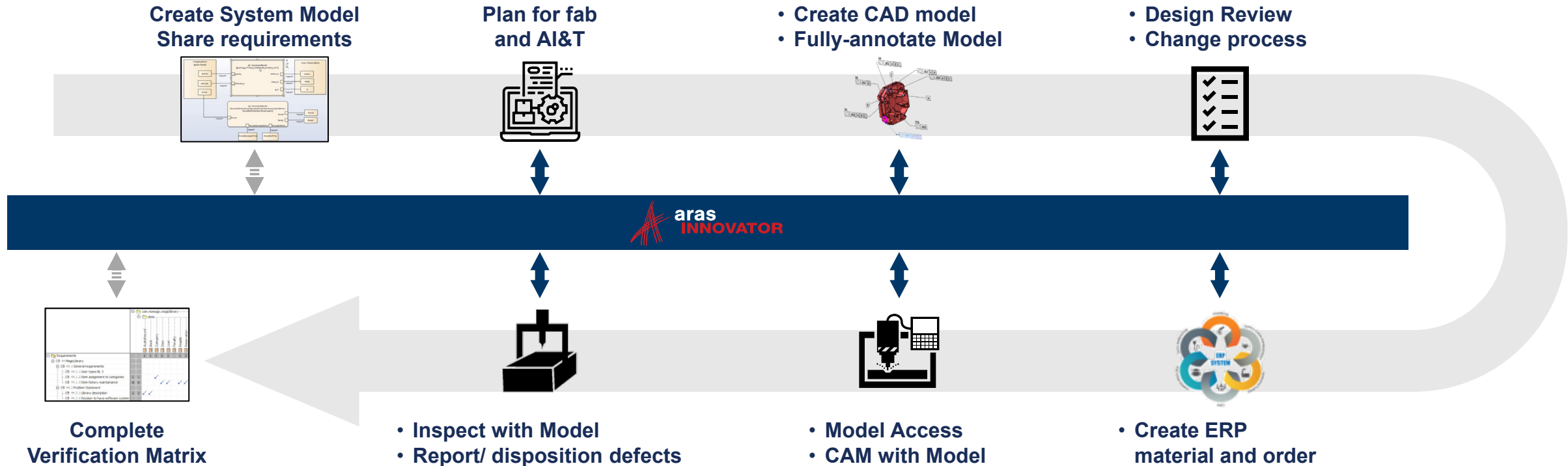


Digital Thread Implementation Strategy From a Systems Point of View





Model-Based Mechanical Part Realization



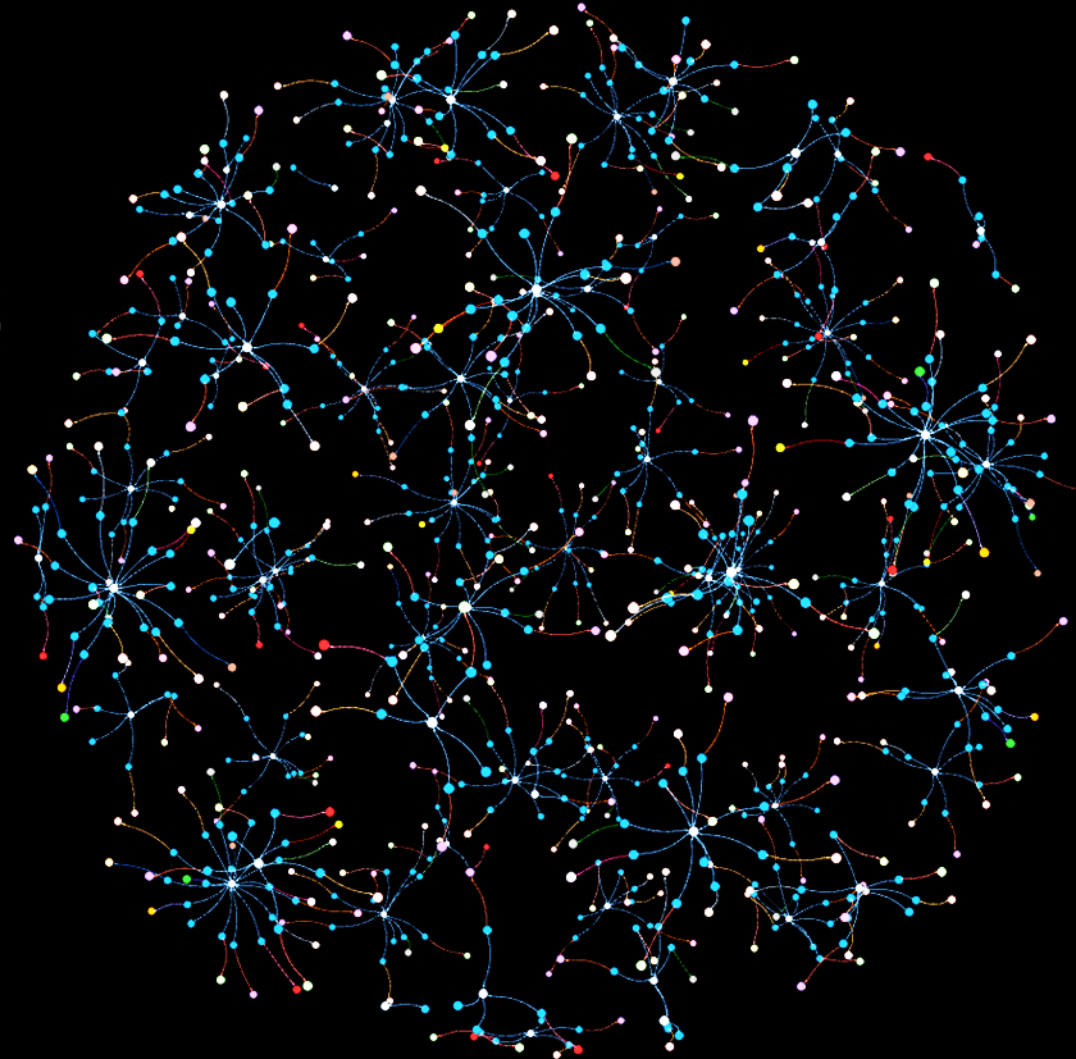
- Linkages and workflows for design to fabrication more streamlined
- All users have access to thread as needed and create new threads
- Data captured and organized right out of the box



Digital Thread Growth

**SEPTEMBER
2023**

**67 Programs
242,000 Data Connections**





Anatomy of a Mechanical Drawing

1. Format
(CAD)

2. Geometry
(CAD Model)

3. Dimensions and
Tolerances
(CAD Model or Drawing)

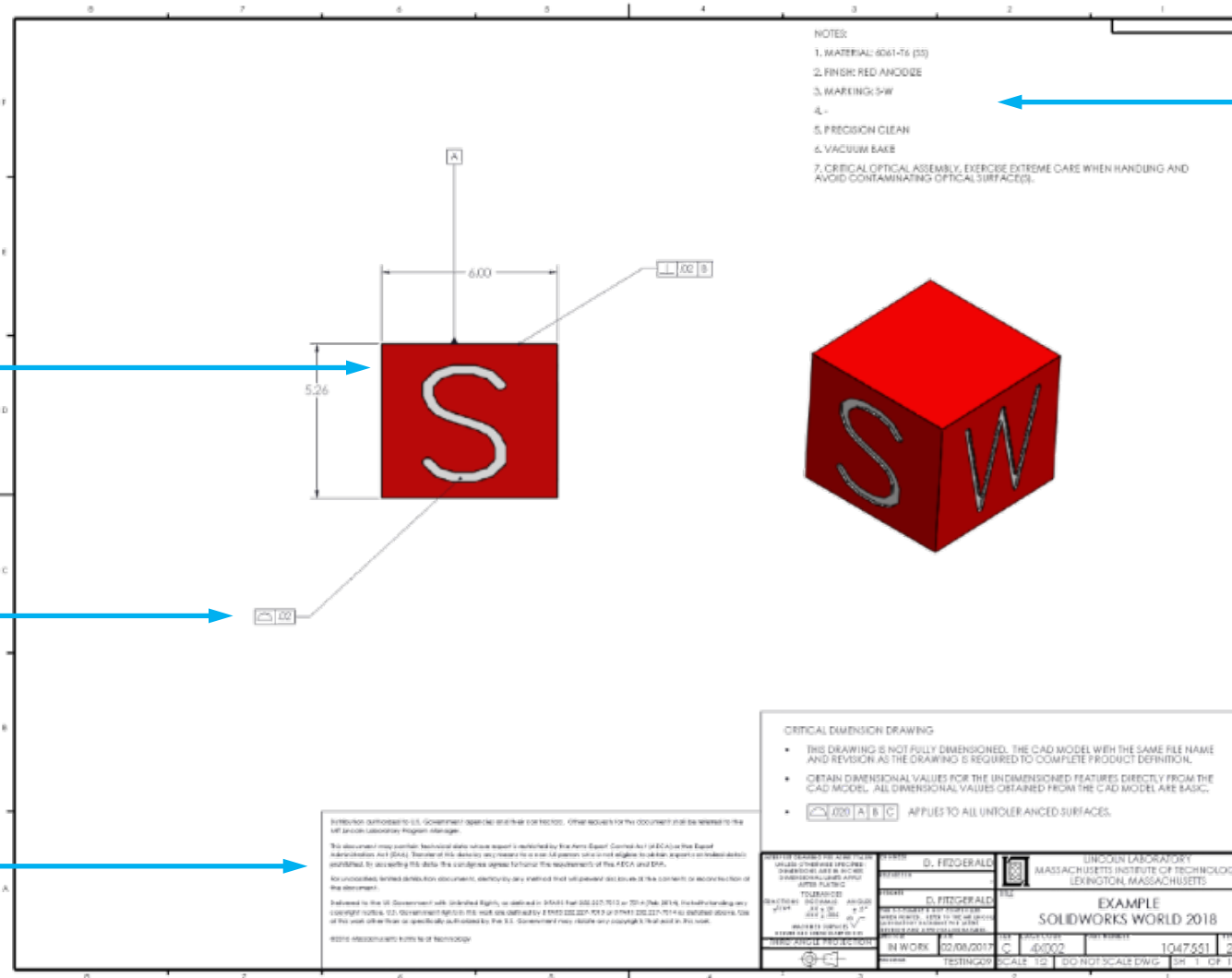
4. Gov Markings
(Lincoln database)

- NOTES:
1. MATERIAL: 6061-T6 (SS)
 2. FINISH: RED ANODIZE
 3. MARKING: SW
 4. -
 5. PRECISION CLEAN
 6. VACUUM BAKE
 7. CRITICAL OPTICAL ASSEMBLY, EXERCISE EXTREME CARE WHEN HANDLING AND AVOID CONTAMINATING OPTICAL SURFACE(S).

5. Manufacturing Notes
(PDM Database)

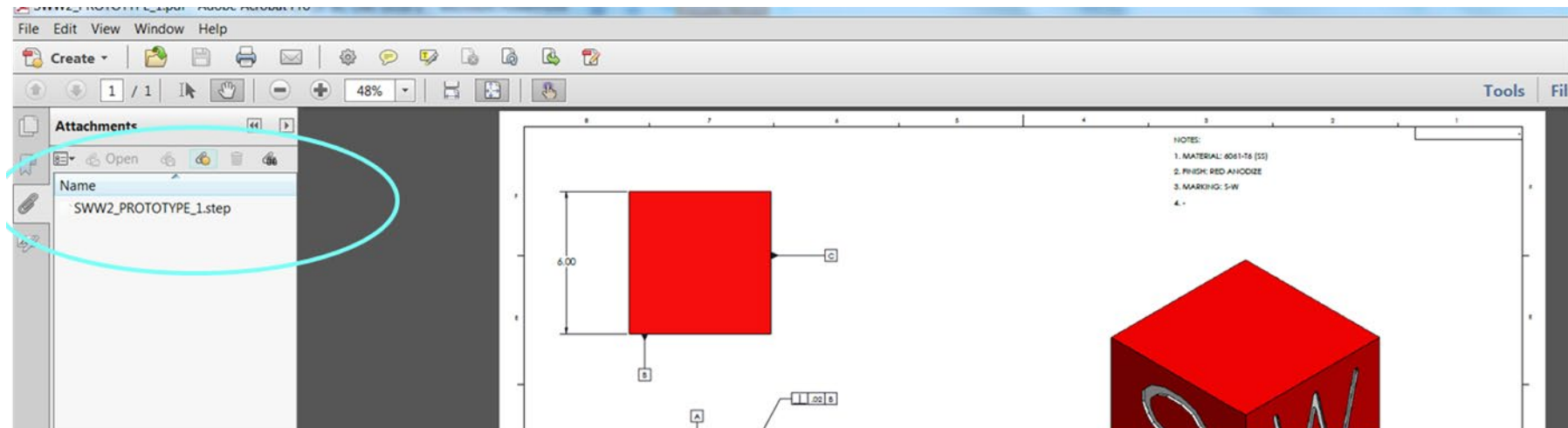
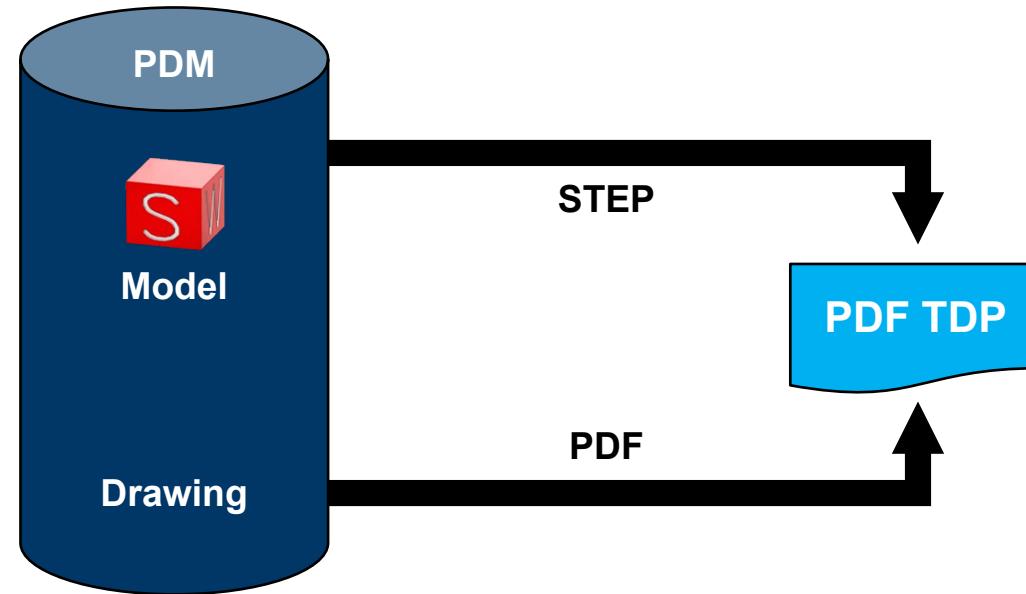
6. Standard Notes
(CAD Format)

7. Title Block Information
(PDM)





Technical Data Package (TDP) Publishing PDM





Part Data Model

Design Part



Material



..... Properties

..... Tests



Material Note

Process Note



..... Document

CAD Document



BENEFITS

- Material and note libraries
- Ability to assign more than one material
- Easy reporting of Material Usage Lists
- Relationships to other supporting documents
- Simplified ECN for non-CAD changes



Notes Interface

aras INNOVATOR

20020290 ☆

Edit [Refresh] [Undo] [Share] [Clipboard] [Share] [More] [Add] [Add]

Part **Process Notes**

Add Note from Template Add New Note Add Material Copy Notes from Part

Process Notes

- 20020290
 - 1. FOR INTERCONNECTIO
 - 2. CABLE ASSEMBLY TO B
REFERENCE IPC/WHMA
 - 3. For size 22D socket cor
713. FOR REFERENCE V
SUGGESTED CRIMPER:
SUGGESTED POSITION
SUGGESTED CONTACT
 - 4. UNLESS OTHERWISE S
 - 5. ASSEMBLY SHALL BE PE
ALL TOOLS AND WORK
ESD APPROVED NITRIL

Process Notes

- 20020290
 - 1. FOR INTERCONNECTION DIAGRAM, SEE DRAWING ?????.
 - 2. CABLE ASSEMBLY TO BE FABRICATED WITH THE FOLLOWING STANDARDS. USE CURRENT STANDARDS VERSION AT THIS DRAWING ORIGINAL RELEASE DATE:
REFERENCE IPC/WHMA-A-620B CLASS 2 REQUIREMENTS AND ACCEPTANCE FOR CABLE AND WIRE HARNESS ASSEMBLIES.
 - 3. For size 22D socket contacts G08S1 or M39029/57-354
713. FOR REFERENCE WITH ITEM ?:
SUGGESTED CRIMPER: M22520/2-01
SUGGESTED POSITIONER: M22520/2-06
SUGGESTED CONTACT INSTALL/REMOVAL TOOL: M81969/14-01
 - 4. UNLESS OTHERWISE SPECIFIED, SHARP CORNERS TO HAVE .010 MAX RADIUS.
 - 5. ASSEMBLY SHALL BE PERFORMED FOLLOWING CLEANROOM PROTOCOL WHERE APPLICABLE.
ALL TOOLS AND WORKBENCH AREAS SHALL BE WIPED WITH ISOPOPYL ALCOHOL PRIOR TO USE.
ESD APPROVED NITRILE GLOVES ARE REQUIRED FOR HANDLING ALL COMPONENTS.

BOM Structure Where Used

Item

20020290

Material Usage List



name
ASSEMBLY 1

Type
Mechanical

Unit of Measure
EA

Design Complexity Level
-

Fabrication Complexity Level
-

Source
Fabrication Service (G007)

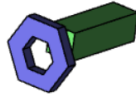
Program
1491_UAT Testing

Comment

Created By: Andrea Lee
Created On: 5/12/2023
Modified By: Innovator Admin
Modified On: 7/7/2023
Locked By:
Major Rev: 3
Release Date: 7/7/2023
Effective Date: 7/7/2023
Generation: 5
State: Released

Changes Pending
 Has BOM

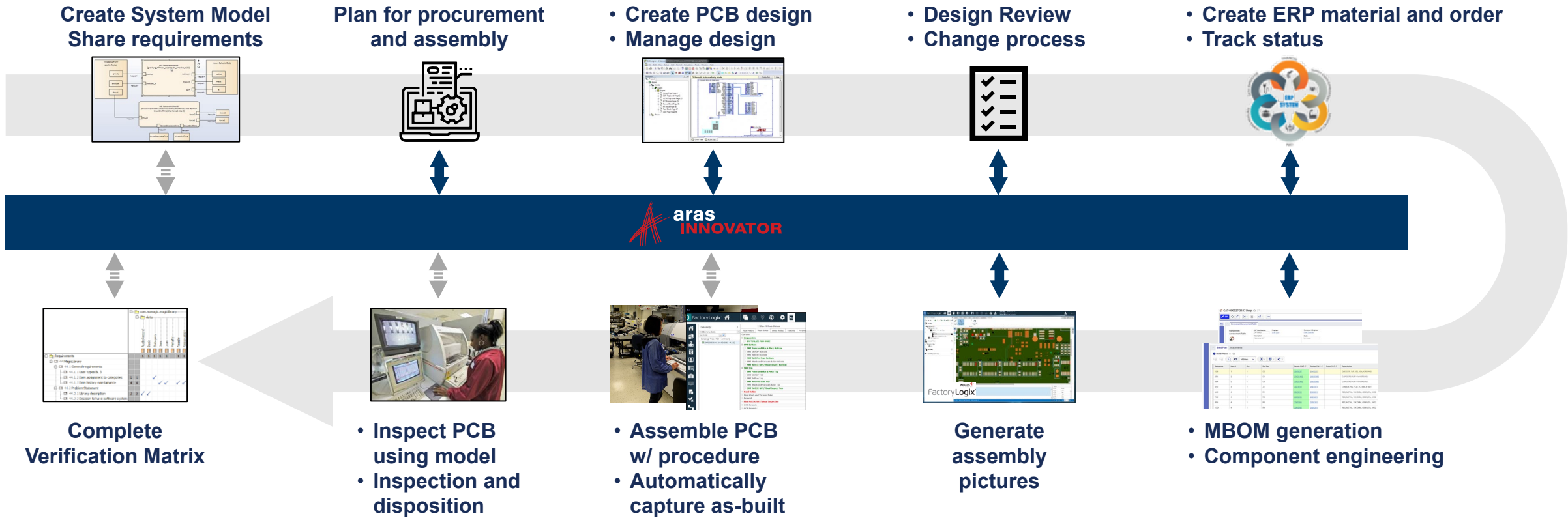
Designated user
Effective Date
7/7/2023 5:19:22 PM
Designer
Andrea Lee
Program Engineer



Item	Note Text	Note Type	Name	Rev	Type	State	BOM Qty	Parent Part Number	Parent Rev	Parent Name	Parent State	Item Type
20020290			ASSEMBLY 1	3	Design Part/Mechani...	Released						Top Part
Process Note	1.FOR INTERCONNECTION DIAGRAM, SEE DRAWING ????.	Cable/System Intercon...						20020290	3	ASSEMBLY 1	Released	Process Note
Process Note	2.CABLE ASSEMBLY TO BE FABRICATED WITH THE FOLLOWING STANDARDS. USE CURRENT STANDARDS VERSION AT THIS DR...	Cable/Assembly						20020290	3	ASSEMBLY 1	Released	Process Note
Process Note	3.For size 22D socket contacts G08S1 or M39029/57-354 713. FOR REFERENCE WITH ITEM ?: SUGGESTED CRIMPER: M22520/2-...	Cable/Tooling						20020290	3	ASSEMBLY 1	Released	Process Note
Process Note	4.UNLESS OTHERWISE SPECIFIED, SHARP CORNERS TO HAVE .010 MAX RADIUS.	Mechanical/Fabrication						20020290	3	ASSEMBLY 1	Released	Process Note
Process Note	5.ASSEMBLY SHALL BE PERFORMED FOLLOWING CLEANROOM PROTOCOL WHERE APPLICABLE. ALL TOOLS AND WORKBENCH ...	Mechanical/Assembly						20020290	3	ASSEMBLY 1	Released	Process Note
20020288			HEX PLATE	2	Design Part/Mechani...	Released	1	20020290	3	ASSEMBLY 1	Released	BOM Part
ALUMINUM 6061-T6; 6061-T651								20020288	2	HEX PLATE	Released	Material
20020289			SQUARE PIN	1	Design Part/Mechani...	Released	1	20020290	3	ASSEMBLY 1	Released	BOM Part
ALUMINUM 6061-T6; 6061-T651								20020289	1	SQUARE PIN	Released	Material
20020289			SQUARE PIN	1	Design Part/Mechani...	Released	1	20020290	3	ASSEMBLY 1	Released	BOM Part
ALUMINUM 6061-T6; 6061-T651								20020289	1	SQUARE PIN	Released	Material



Model-Based Printed Circuit Board Realization



- Enables integration of circuit design simulations into the larger electrical, thermal, optical, and mechanical system design for earlier verification
- Consistent thread created throughout process

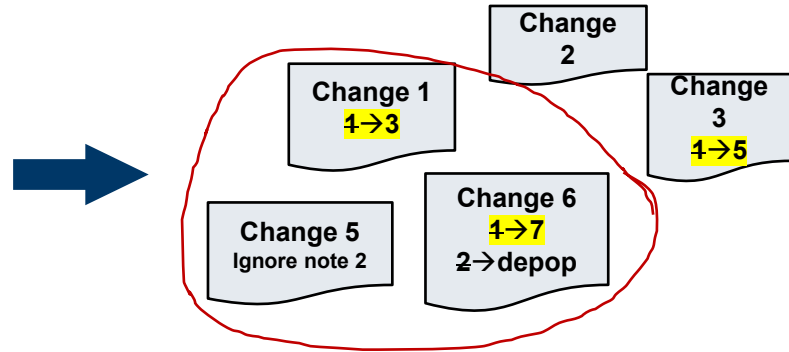
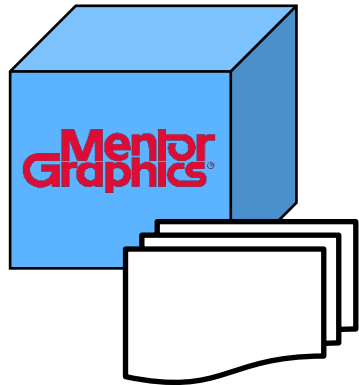
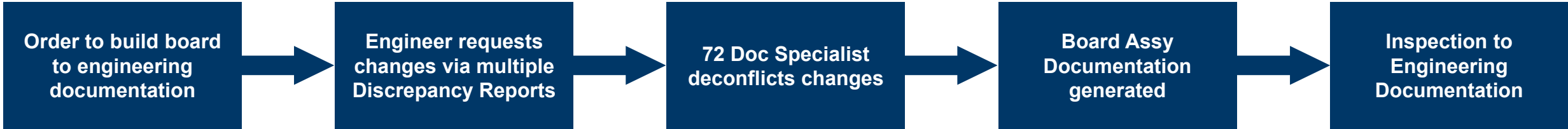








Benefits

- **Significant data reuse**
- **Alignment on communication between roles**
- **Consistent source of truth**
- **Less data entry**
- **People do not need to be the source of truth**
- **Results 20 pilot builds**
 - **215 hours saved manual data entry**
 - **429 parts created automatically**
 - **Automated reuse of parts**
 - **Improved inspection workflow**



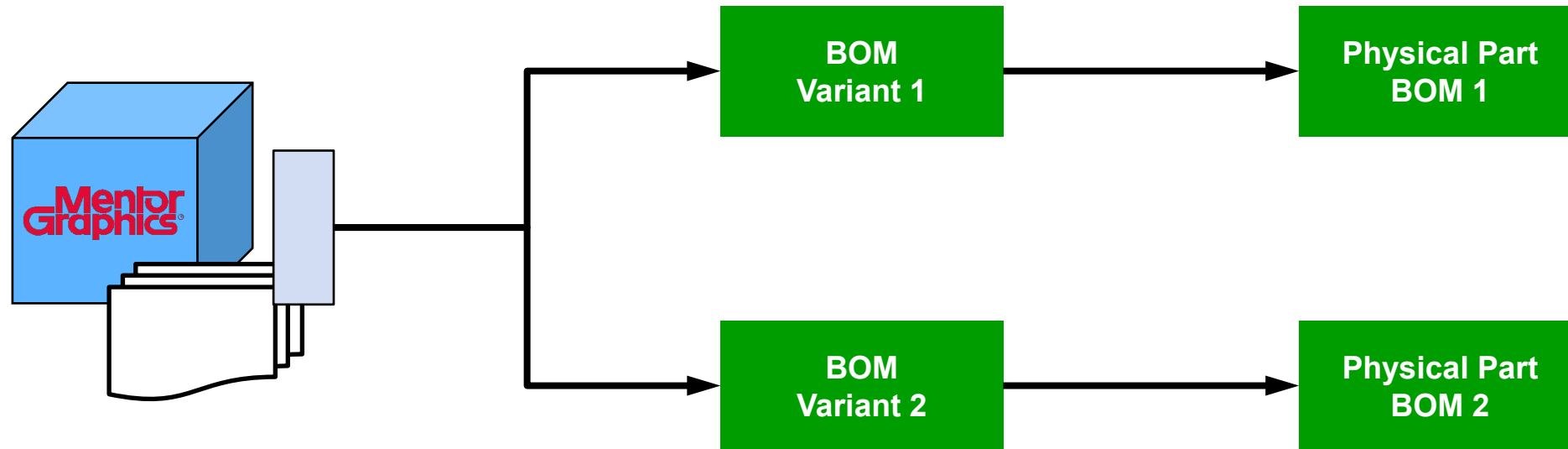
Legacy Process – Fabrication Change Orders



-   Engineer approves the request for change, but not the resulting design
-   Process relies on an individual to clarify conflicting documentation
-   Inspection didn't have a single document to show design that was built



Transformed Process





Build Plan MBOM Interface

The screenshot displays the 'Build Plan' interface for BLD109. The top section contains metadata fields for Build Number (BLD109), Revision (1), and State (Released). It also includes fields for Description, Design BOM (20006114), Program (2951 Chickadeeish), Design BOM Rev (1), Design BOM CAT (CAT-000034 2951 Chickadeeish), and checkboxes for 'Accept Incomplete Assessment' (Yes) and 'Requires Unit Engineer Approval' (Yes). A 'Build Plan Key' legend is visible, with categories: Matches CAR (green), Does Not Match CAR (blue), Override Modification (purple), and CAR In Process (yellow).

The bottom section shows a table of parts with a context menu open over the first row. The table has columns: Sequence, Item #, Result PN [...], Design PN [...], From PN [...], Description, Fab PN [...], CAR State, and Lead Forming.

Sequence	Item #	Result PN [...]	Design PN [...]	From PN [...]	Description	Fab PN [...]	CAR State	Lead Forming
128		20009494	20009494		CAP, ALUM, 22UF, 20%, 25V, RADIAL	20009494	Unnecessary	
256		2003004	2003004		RES, FILM, 39.2K OHM, 1/8W, 1%, 1206	2003004	Unnecessary	

- Consistent, simple to use interface to create MBOM
- Generates inputs for downstream kitting, build, and inspection



Component Engineering

The screenshot shows the aras INNOVATOR software interface. The main window displays the 'Component Assessment Table' for 'CAT-000003 3381 Program 3381'. The table has the following columns: Part Number, Description, Fab Part, Lead Forming, Upscreen, Programming, and Mitigation. The data rows are as follows:

Part Number ...	Description	Fab Part [...]	Lead Forming	Upscreen	Programming	Mitigation
20005894	OPTOCOUPLER, SINGLE-CHANN...	20007683	No	Yes	No	No
2059979	IC, RGMII, SINGLE PHY, RADH, V...	20006896	Yes	No	No	Yes
20006701	EXTMP XFMR	20006701	No			No
20006720	MDL, SGL, 1000B, 1:1, SMT, TU P...	20006720	No			No

- Automated creation reuse, structuring, and replacement of components based on requirements
- Parts and component assessment reusable, requirements unique from program to program



Physical BOM – Digital Twin Foundation

20012847 ☆ []

[Edit] [Refresh] [Undo] [Share] [Print] [More]

Physical Part

SerialNumber: 10 Batch Number: Q000000694 Owner: Rick Magliocco FSR: FSR-000575 Precision-Cleaned: [] Characterized: []

Part Reference: 20012847 Part Ref. Rev: 1 Physical Part State: Exists Program: 3381_3381 PPR: 6001592_53137200 Vacuum Baked: []

Has BOM: Part Name: Arduino_Isolation_Shield_R1 ASSY Actual Location: Web Service Error PPR Item: 0000003439

Has Deviations: Category A: [] Certified: No Qty Available: 0.000 Comments: []

Physical Parts [] ☆

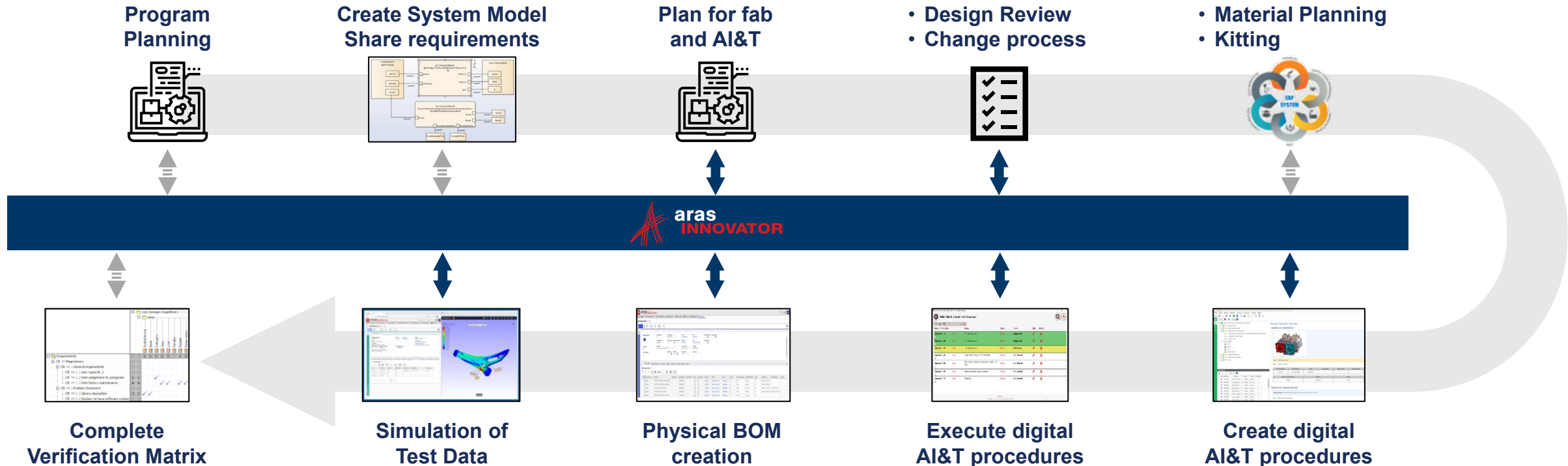
[Search] [X] [Hidden] [Refresh] [Print] [More]

Part Reference [...]	Part Name	Part Ref. Rev	Batch Number	Serial Number	Has B...	Has Deviation	Program [...]	PPR [...]	FSR [...]	Certified	Physical Part State	As-Built BOM State	Line No.	Install Date [...]	Removal Date [...]	Quantity
2020477	TEST POINT, THRUHOLE, WIRE LOOP, RED	-	TMP0002829		<input type="checkbox"/>	<input type="checkbox"/>	3381_3381	6001591_53137159	FSR-000566	No	Exists	Installed	128	6/8/2023 1:18:56 PM		1
2027476	TEST POINT, PC, COMPACT, .063"D, ORN	-	TMP0002830		<input type="checkbox"/>	<input type="checkbox"/>	3381_3381	6001591_53137159	FSR-000566	No	Exists	Installed	256	6/8/2023 1:18:56 PM		2
2044139	CAP, 0.1UF, 50V, 10%, X7R, 0603	-	TMP0002816		<input type="checkbox"/>	<input type="checkbox"/>	3381_3381	6001591_53137159	FSR-000566	No	Exists	Removed	384	6/8/2023 1:18:56 PM	12/18/2023 8:14:59 ...	1
2052786	CAP, CER, 10UF, 16V, 20%, 0805	-	TMP0002817		<input type="checkbox"/>	<input type="checkbox"/>	3381_3381	6001591_53137159	FSR-000566	No	Exists	Removed	512	6/8/2023 1:18:45 PM	6/8/2023 1:18:50 PM	4
2030783	TEST POINT, PC, COMPACT, .063D, YEL	-	TMP0002828		<input type="checkbox"/>	<input type="checkbox"/>	3381_3381	6001591_53137159	FSR-000566	No	Planned	Allocated	640			2

• Complete thread carried through to as-built physical BOM



Systems Engineering through System Build and Test



- Data created in all aspects of design reused for assembly and test procedures
- Digital procedures break down information for reuse
- Complete thread from requirements to completion



Digital Procedures

MPP-10004 ☆ □



Location: [] Language: English [v]

- 1 : Verify the profile
- 2 : Mount the unit onto the shaker.
- 3 : Mount the accelerometers.
- WC-0002
- T-000002
- M-000002
- S-0008
- S-0001
- 20 : Vibration
 - 1 : Run the X-axis.
 - 2 : Rotate the mounting to the Y-axis.
 - 3 : Run the Y-axis.
 - 4 : Rotate the mounting to the Z-axis.
 - 5 : Run the Z-axis.
- WC-0002
- M-000002
- S-0008
- 30 : Thermal
- 40 : Assembly

Y-Axis

Step 4 : Rotate the mounting to the Z-axis.
Step 4 Description: Mount with 8x 1/4-20 bolts. Torque to 20 in-lbf.

Step 5 : Run the Z-axis.

Figure 9



Z-Axis

Resource Number	Name	Type	Quantity
WC-0002	Environmental Test Lab	Work Center	
M-000002	Shaker Table	Machine	

Workbench

Parts [v] Search []

Part Number	Name	R.	Mak...	Type	State
20020288	HEX PLATE	2	Make	Design ...	Released
20020289	SQUARE PIN	1	Make	Design ...	Released

[Operation 30 : Thermal](#)

[Operation 40 : Assembly](#)

Step 1 : Testing bullets/lists

Step 1 Description: 1) Do a thing for a while and record some data. 2) Do a different thing for a while. 3) Reset a feature and get into position. 4) Align a tool to the feature so that it is ready do do a test. 5) Do the first again in the new positioning. 6) Measure to see how it compares to the start. 7) Repeat as many times as needed until the recorded value is in range.



Digital Breakdown

MPP-10004

Process Plan

Process Plan

Process Plan Number MPP-10004 **Revision** 3 **State** Preliminary **Created On** 7/14/2023 4:56:30 PM
Created By [Joseph Flaherty](#)
Program [1491 UAT Testing](#)
Assembly Overview Template [TDP_Frontmatter...](#)

Controlled Unclassified Info
 No

Title
 AI&T Evaluation

Mission
 Checking out the content

Type
 Test Procedure

Has Changes

Parts Under Test Locations Assembly Overview Documents Fixtures **Machines** Skills Test Software Tools Work Centers Step Assoc Rqmts Step In

Part Number	Private Type	Name	Configuration	Revision
20020290		ASSEMBLY 1		3

Page: 1

MPP-10004

Process Plan

Process Plan

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Controlled Unclassified Info
 No

Title
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Mission
 Checking out the content

Type
 Test Procedure

Has Changes

Parts Under Test Locations Assembly Overview Documents Fixtures **Machines** Skills Test Software Tools Work Centers Step Assoc Rqmts Step In

Number	Name
MPP-10004	
Operation Operation 10: Set up the test	Set up the test
M-000002	Shaker Table
Operation Operation 20: Vibration	Vibration
M-000002	Shaker Table
Operation Operation 30: Thermal	Thermal
Operation Operation 40: Assembly	Assembly



Execution Record

Record MER-10001: MPP-10004 AI&T Evaluation, Revision 1

Execution Record

Created By: Joseph Flaherty
Created On: 7/18/2023
Modified By: David Radue
Modified On: 7/18/2023
Locked By:
Major Rev: A
Generation: 1
State: In Creation

Process Plan: MPP-10004
Process Plan Number: MPP-10004
Process Plan Name: AI&T Evaluation
Process Plan Description: Checking out the content
Sub-Procedure Note: N/A

Record Number: MER-10001
Process Plan Number: 1
Reviewer:

Has Redline:

Execution View Execution Test Parts Compare Bombs Execution Operations Redlines Technicians

Redline Records

Created On [...]	Created By [...]	Redline Number	Type	Effectivity	Redline Note [...]	Image [...]	History [...]
7/18/2023 3:47:00 PM	David Radue	RL-00003	Step Input - Add OR Update	Permanent			New Step Input 'Adjust Accelerometer Placem...
7/18/2023 7:08:20 PM	Melissa Phelan	RL-00004	Step - Add OR Update	Awaiting Review			New Step 'Setup the Over' added during execut...
7/18/2023 7:08:39 PM	Melissa Phelan	RL-00005	Step - Add OR Update	Awaiting Review			New Step * added during execution on operatio...
7/18/2023 7:09:17 PM	Melissa Phelan	RL-00006	Step - Add OR Update	Awaiting Review			New Step * added during execution on operatio...
7/18/2023 7:09:36 PM	Melissa Phelan	RL-00007	Step - Add OR Update	Awaiting Review			New Step * added during execution on operatio...



Digital AI&T Related Tasks

Role	Tasks	Automated
Tech Writer	Update Procedures	✓
	Reconcile Changes	✓
Unit Engineer	Reconcile build	✓
	Understand change	✓
Systems Engineer	V&V	✓
	Data collection	✓
Analyst	Find data	✓
	Validate design	
Mission Assurance	Verify pedigree	✓
	Reporting	✓

- Reduced data access from 7-8 systems to 1
- Reduced time to update procedures
- Reduced reconciliation time 2-10 hours
- Reduced time to generate reports- days



Conclusion

- **We found value in connecting people and connecting data**
- **Digital thread**
 - **Improved quality**
 - **Reduced manual labor for administrative tasks**
 - **Reduced system access**