Unlocking the Value of Digital Manufacturing Data:

A Standards-Based Approach to Persistent IDs (PIDs)

GLOBAL PRODUCT DATA

INTEROPERABILITY

SUMMIT 2025

BOEING ELYSIUM LOCKHEED MARTIN NORTHROP GRUMMAN Parker PDES, Inc.® Connecting the Digital Enterprise

Stephanie Locks-Hartle – Lockheed Martin
Nathan Holyoak – Northrop Grumman

Lockheed Martin PIRA Approved: CHQ2025080353

Agenda

- **Who we are**
- **Introduction to Persistent Identification (PIDs)**
- **University Research projects for PIDs**
- **Vendor Assessment**
- **Future efforts**
- **Wrap up/Questions**

Teaming Arrangement and Project Coordination

Primes

Drive adoption in timely manner
Influence software vendors

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NORTHROP GRUMMAN

Collaboration with Software and Equipment Vendors

Develop PID Capabilities

MasterCAM; Hexagon; Zeiss; Polyworks; Metrologic; Dassault; Siemens; PTC

Standards Organizations

Ensure compatibility across standards

MTConnect; PDES; DMSC; ASME; NIST

Demonstrations

Proof of Concept

Georgia Tech; Purdue; Rensselaer

Presenters Bio 1

Nathan Holyoak is a Senior Engineering Manager at Northrop Grumman with an extensive history of rocket motor design. He has led the Digital Design and Integration team in the CAD creation and integration of new solid rocket motor designs as well as supporting historical rocket motor programs. He has worked in depth with product lifecycle management. Writing new configuration management compliant process and ensuring proper workflow and legal requirements. He has worked with DOD and NASA on ensuring that accurate and articulate technical data packages were created.

Nathan has a long history of hands-on experience with mechanical and electrical systems. He has also been intimately involved in manufacturing process. Since joining the aerospace and defense community Nathan has worked as tool engineering designing highly specialized rocket motor tools. He has also worked with the electrical design teams to create ECAD digital logic diagrams that flow into cable diagrams that flow into MCAD virtual physical models.

His appreciation for the operators and those who make hardware drives him to ensure they are included. He spear headed the virtual reality usage as part of the design sign off process so operators could look at virtual engineering data and give feed back years before they would have to make hardware.

Prior to joining aerospace and defense Nathan owned and operated an automotive repair facility that specialized in automotive electrical systems. Nathan is comfortable in the unknown and strives to look for answers in the unlit areas of the problem.

Nathan’s work with persistent identification is a natural fit. He views it as a requirement as we work more in a world where machines talk to machines. The need to have nonchanging connection points he sees as a requirement not just a nice to have.

Nathan has an MBA, BS/MS-Mechanical Engineering, AS-Auto Collision Repair. He is Siemens NX CAD certified, CMII certified, and holds automotive certifications from ASE and I-CAR. Nathan has published in both industry and company papers.

Presenters Bio 2

Stephanie Locks-Hartle is a seasoned data scientist and manufacturing expert with a strong background in leading cross-functional teams and driving digital transformation in the aerospace and defense industry. Currently, she serves as a Data Analytics & Data Science Project Lead at Lockheed Martin Corporation (LM), where she has successfully led the development of analytics solutions that have generated significant returns on investment.

With a proven track record of driving innovation and process improvement, Stephanie has established herself as a subject matter expert in data analytics, data science, and digital manufacturing. She has led the development of Persistent Identifiers (PIDs) to enable causal analytics and has collaborated with industry partners, including Northrop Grumman Corporation, to implement standards-based PIDs.

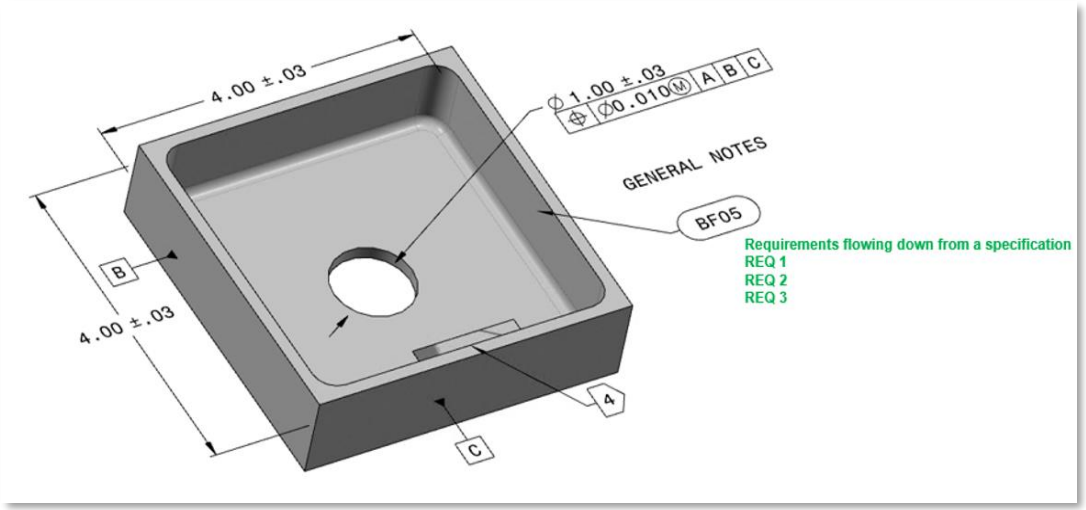
In addition to her technical expertise, Stephanie is passionate about developing the next generation of data analytics professionals. She is the instructor for the LM Data Analytics Apprentice Program, where she teaches and mentors apprentices in data analytics and data science for manufacturing. She has also designed the syllabus and courses for the program, demonstrating her commitment to knowledge sharing and talent development.

Stephanie holds a Master's degree in Mechanical Engineering from the Georgia Institute of Technology and a Bachelor's degree in Mechanical & Aerospace Engineering from Cornell University. She is a recipient of several awards, including the 2021 STEP Ahead Award from the National Association of Manufacturers and the 2019 Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers.

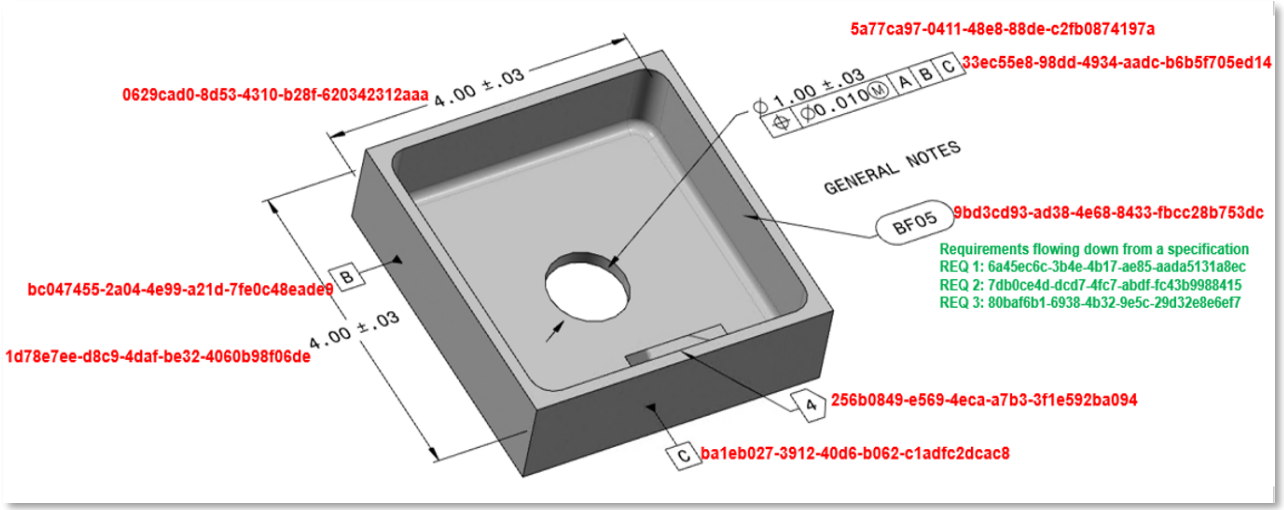
Introduction to Persistent Identification (PIDs)

Persistent IDs are unique values tied to discreet features that are consumable & support digital thread automation

What the human sees



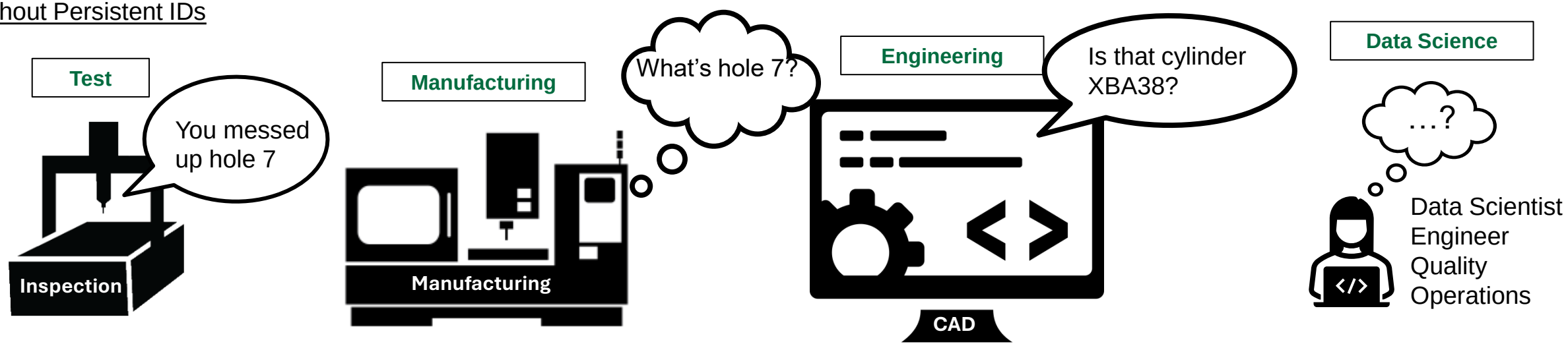
What the machine/system sees



Persistent IDs Identify the geometry and PMI across engineering, manufacturing and inspection systems

Introduction to PIDs - Tracing a failure (One of many use cases)

Without Persistent IDs



With Persistent IDs we have traceability

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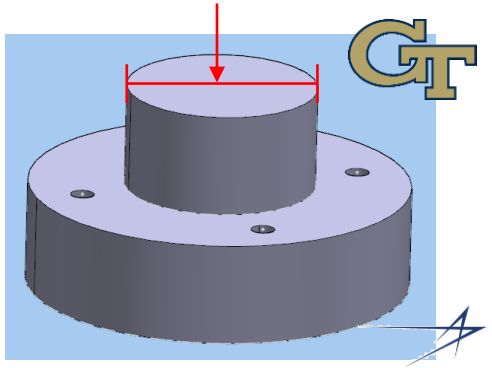
University Research - Project Layout

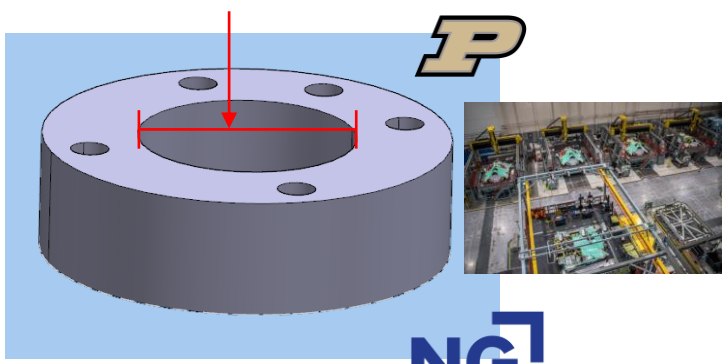
Project Summary: Demonstrated a use case where PIDs in STEP file persisted in an automated way through the production and inspection process to provide value. Demonstrated case was having PIDs be used to predict how parts in an assembly would fit together prior to being geographically co-located. Discovered needed more items to have PIDs for use case.

Boss OD = 1.497 ± 0.003



PN111

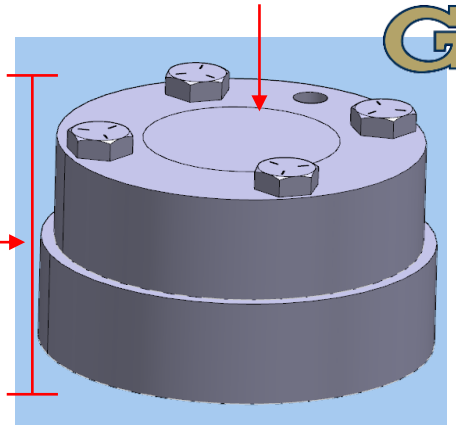
ID = 1.500 ± 0.003



PN222

***PN111* Boss OD < *PN222* ID**

Overall Height = 1.600 ± 0.005



LM had GT make 25 parts, NG had Purdue make 25 mating parts, GT took persistent ID tagged data and predicted which assemblies fit best together before receiving the parts from Purdue. GT then assembled parts and compared predictions to actual results.

Inspiration – Could we use PIDs to predict or eliminate shimming between the F35 Fuselage (NG) and the body of the aircraft (LM)? Could we use PIDs to reduce the number of assemblies that would be scrapped?

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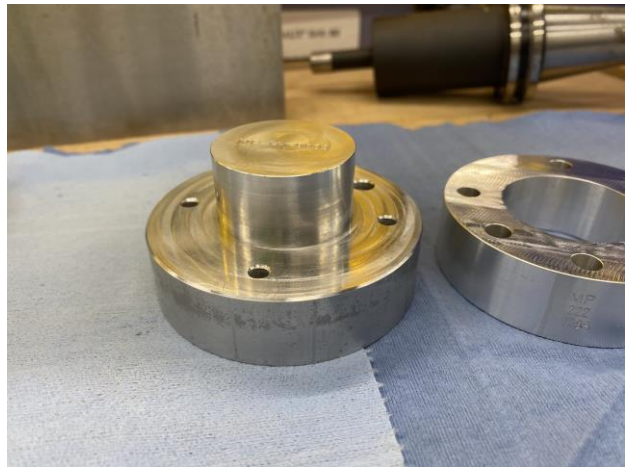
University Research - Goals for GT & Purdue

- **Create automated solution to tag key features and characteristics with UUIDs in the STEP file.**
- **Ensure PIDs ‘persist’ through CAM, In-process mfg data, and Inspection data in an automated way**
- **Use PID tagged data to optimize assemblies**



Tag it

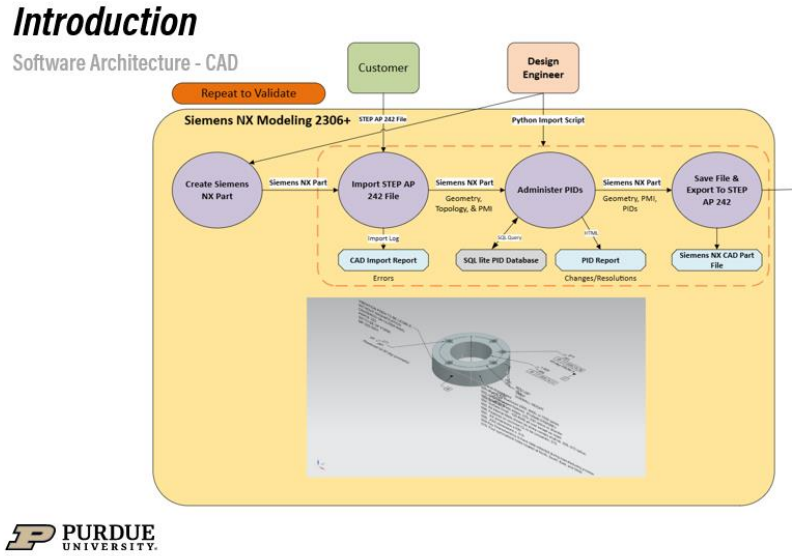
Trace it

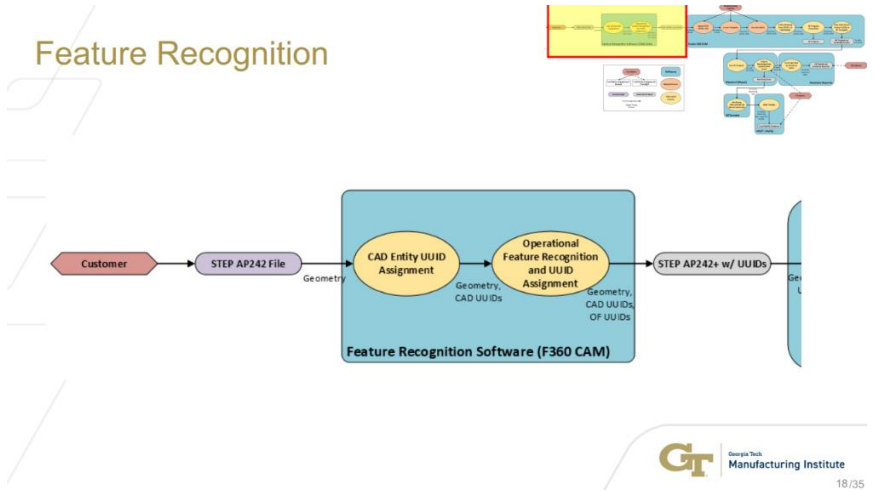
Optimize it

University Research – Automated Approach for tagging PIDs

Tag it

- **Georgia Tech and Purdue took similar approaches**





1. Take in STEP AP242 file
2. Use automated code to map from ‘CAD Features’ to ‘Operational Features’
3. Assign PIDs to ‘Operational Features’
4. Add ‘Operational features with PIDs’ to bottom of STEP File

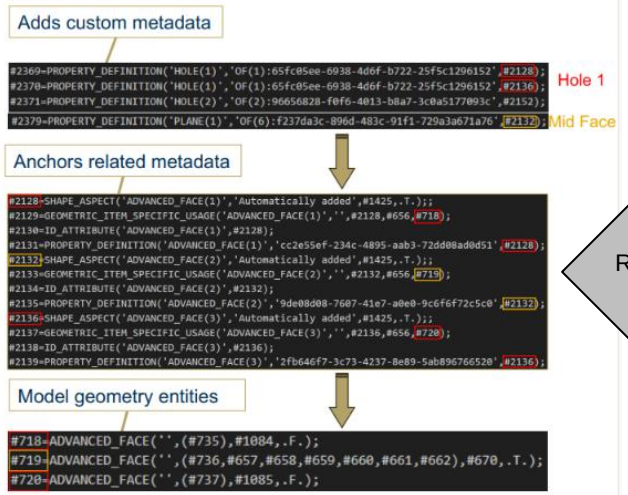
University Research - Key Differences Between Approaches for Adding UUIDs

Tag it

- **There were a couple key differences between Purdue and Georgia Tech – Mainly Georgia Tech took a approach that followed the AP242 Schema.**
- **When they appended the Operational feature and PID information at the bottom, there was a ‘Rosetta stone’ in between to map between the CAD features and the Operational Features.**
- **This updated AP242 doc with PIDs was ‘dubbed’ the AP242+ file**

UUIDs in AP242 STEP Format

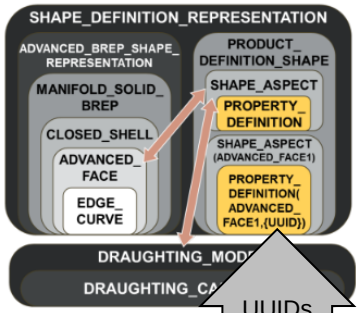
- Operational Feature UUIDs appended as AP242 PROPERTY_DEFINITION entities linked to SHAPE_ASPECTs
- GISU entity links the SHAPE_ASPECT to highest level CAD face/edge entity
- Nested entities within tagged face/edge entities allow for automated design modification



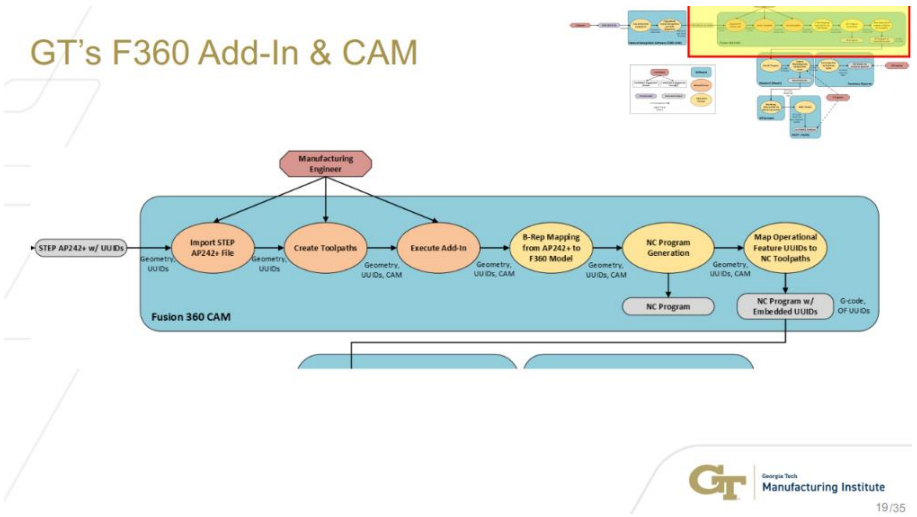
Rosetta Stone

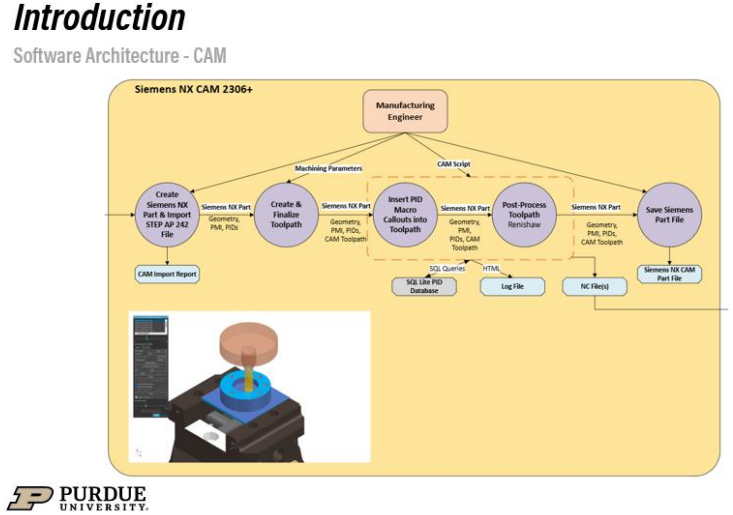
AP242+ Preview

- AP242 standardizes model geometry and PMI representation
- Implemented an automated process for linking persistent identifiers representing **features requiring a manufacturing plan** (i.e. “operational features”) to model geometry
- Downstream feature process data can be directly linked to model geometry, to the defining edges and vertices
- GD&T/notes/datum tied to model geometry can be linked to specific feature identifiers



- **Both approaches were similar**
- **Input STEP AP242 file with PIDs**
- **Use CAM tool to generate toolpaths**
- **Run custom script to capture when a toolpath is working on a specific PID**
- **Use Renishaw solution to insert into G-code the proper PID for the appropriate lines of G-code**



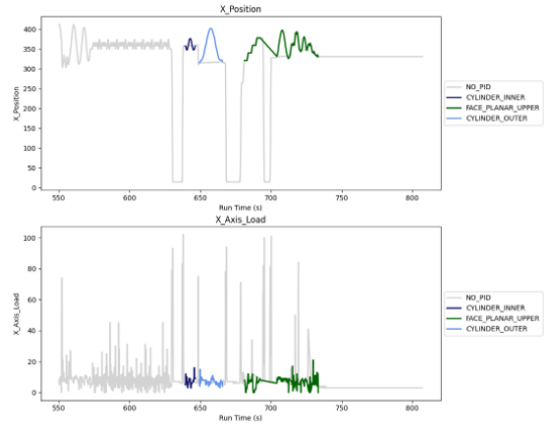


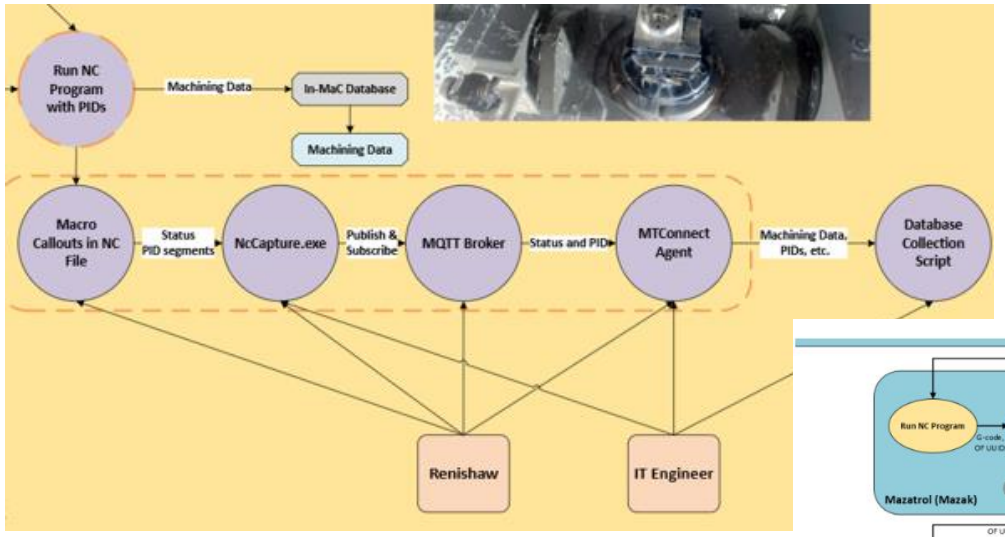
University Research - Using the PIDs to Look at In Process Mfg Data

Trace it

- **Approaches were able to output MTConnect data tagged with ‘Starts’ and ‘Stops’ for PIDs**
- **High frequency data such as audio data can be correlated with the MTConnect data to also understand when PIDs were worked on**
- **Solutions inspections output directly to QIF files that contained the PIDs. Two different approaches were taken to output the QIF file**

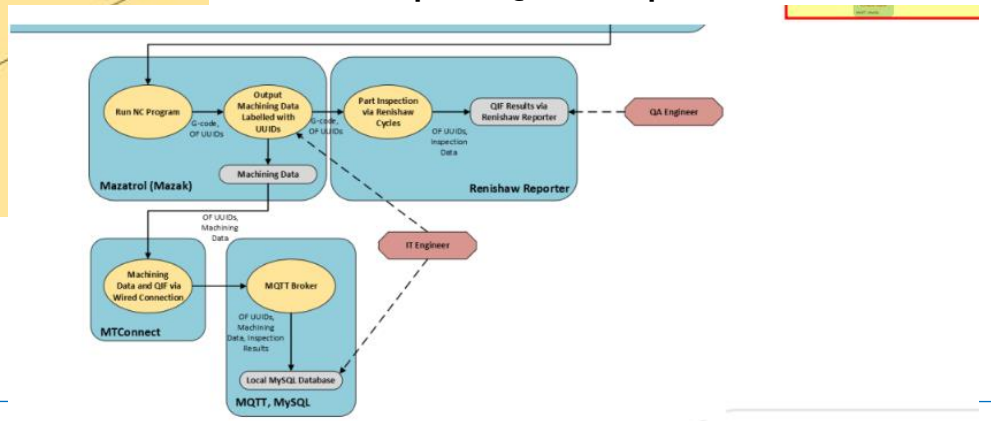
Real tagged MTConnect data with PIDs



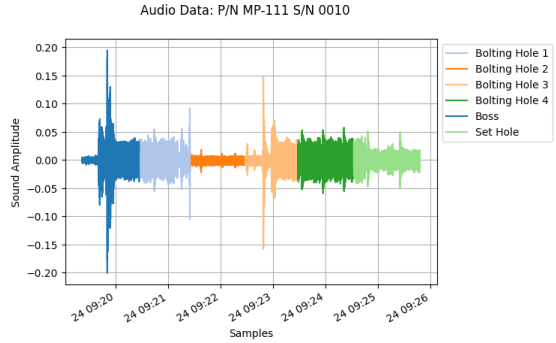


Output MTConnect data

Output QIF Report



Audio data mapped with PIDs



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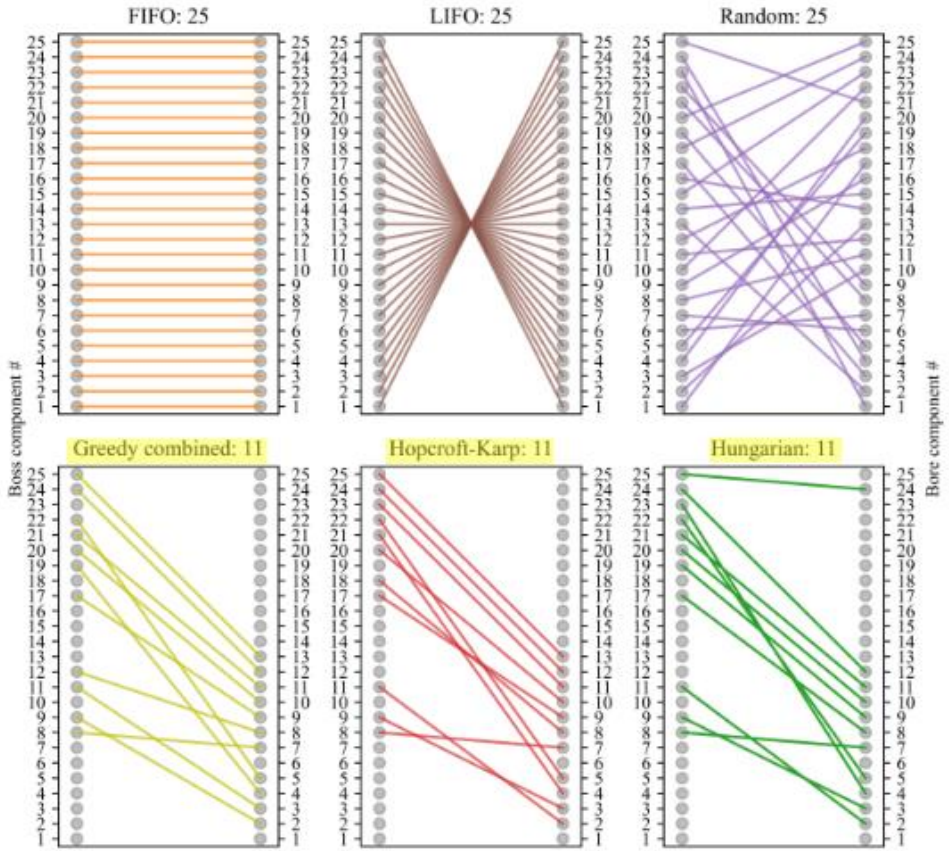
Optimize it

Typical Approaches

Data Driven Approaches

Comparison of Matches Across Methods



- Uninformed heuristic matching shows high match rate, but does not represent valid matches
  - Further filtering of matches is needed to evaluate heuristic baselines
- Advanced optimizations result in the same number of matches
  - There is no unique, optimal solution

Georgia Tech

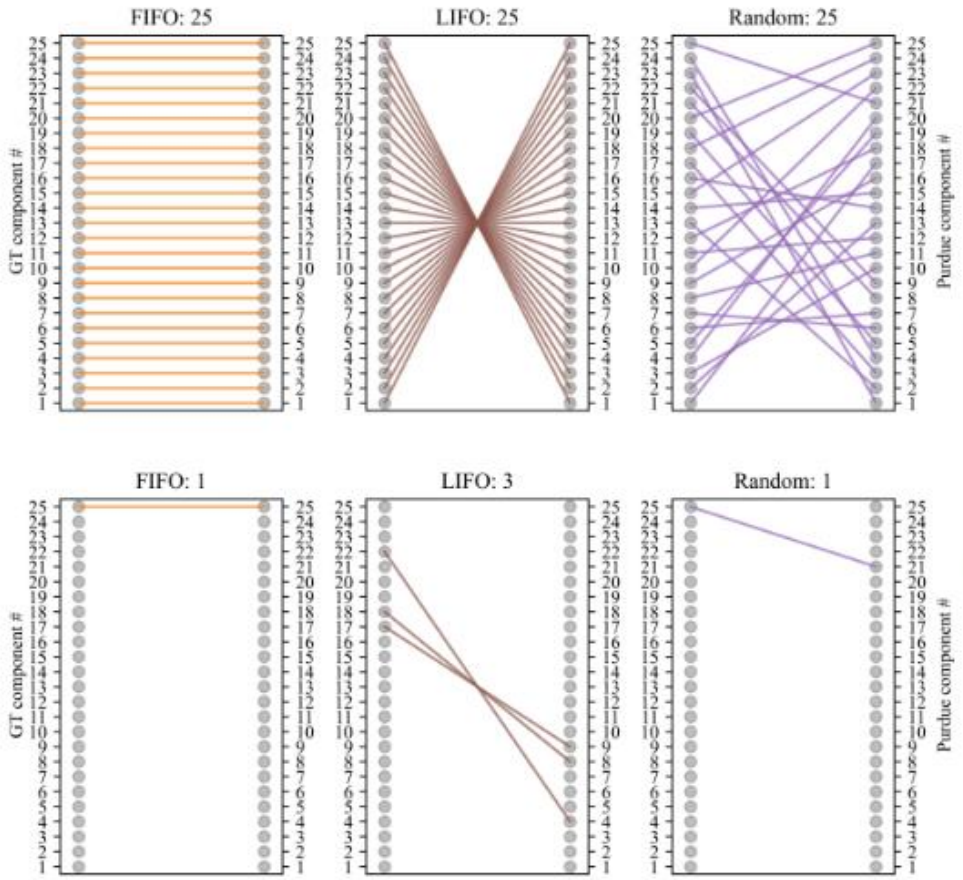
University Research - Heuristic modeling reality check

Optimize it

Typical Approaches

Informed Heuristic Matching

Passing FIFO, LIFO, Random through second, filtering stage shows represents reality more closely



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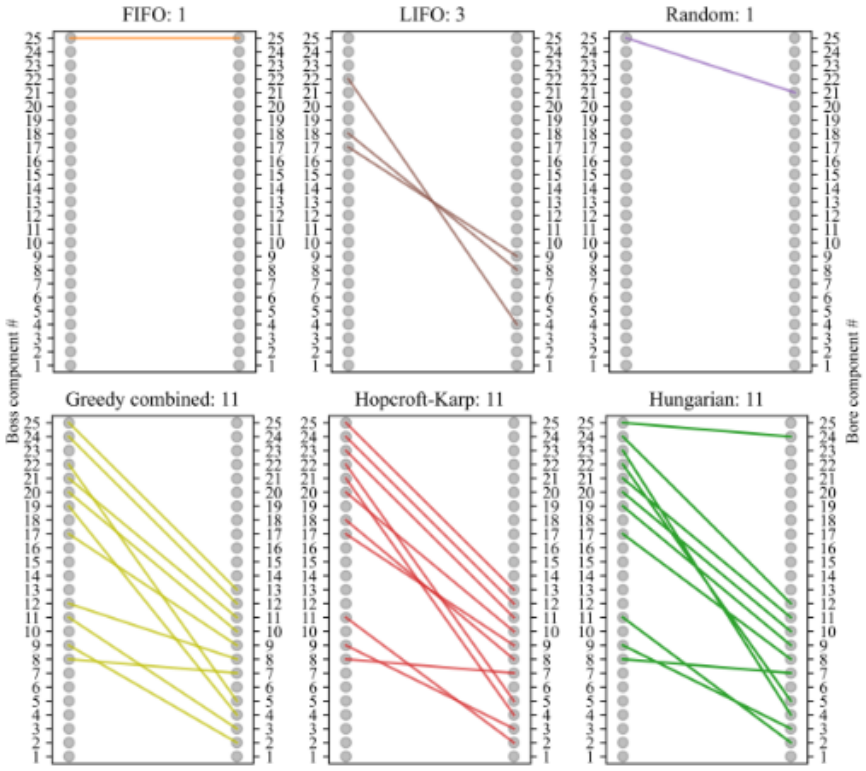
Georgia Tech

University Research - Did they fit?

Optimize it

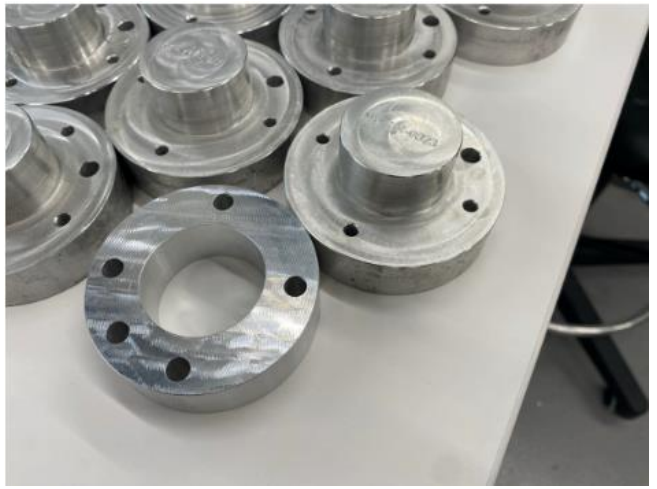
Validation of Valid Matches



Some matches satisfy assembly tolerances according to data, but do not physically fit together

FIFO (1)	1 match / 0 no match
LIFO (3)	2 match / 1 no match
Random (1)	1 match / 0 no match
Greedy (11)	11 match / 0 no match
Hopcroft-Karp (11)	9 match / 2 no match
Hungarian (11)	8 match / 3 no match

For baseline heuristic methods, there are very few assemblies that meet inspection criteria after a logic filter. In reality, there are even fewer parts that actually fit together.



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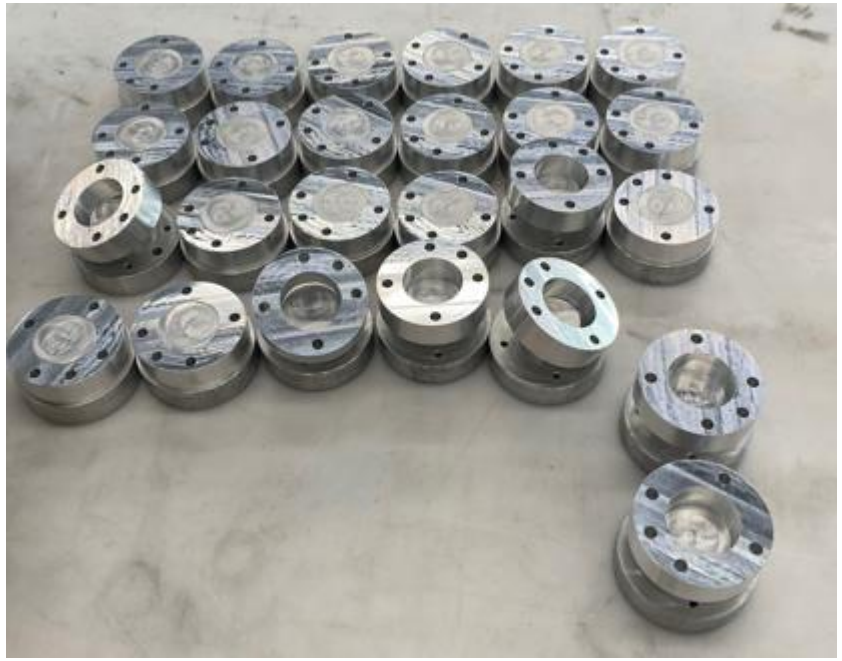
University Research - Take Aways

Tag it

Trace it

Optimize it

- **Using data driven approaches we found more matches than pure heuristic approaches (i.e. FIFO) but predictions weren't always accurate. Would have been better if more operational features and characteristics had been tagged with PIDs**
- **Automated approach for creating operational features and assigning them a PID was a 'must' for this to scale for even a couple operational features**
- **Solution for AP242+ File was a key finding in making this a success. Needed a way to map from CAD Features to what we would be tracking and inspecting (aka Operational Features and Characteristics)**
- **More automation is needed from CAx vendors to support this approach. Would like to see CAD vendors generate the AP242+ file with the mapping to Operational features for the rest of the CAx vendors to use.**



A big thank you to the teams who performed this work!

Georgia Tech:
Melissa Foley, Matthew Kosmala, Shohom Bose-Bandyopadhyay, Dr. Tom Kurfess, Dr. Kyle Saleeby

Purdue:
Sam Stencel, Larry Fultz, Dr. Ben Haley, Dr. Nathan Hartman

If you are interested in learning more about these projects, email Stephanie.Locks-Hartle@LMCO.com or Kyle.Brand@ngc.com

Vendor Assessment – Approach

Approach

1) Initial mass outreach to potential vendors in three specific areas
    1) CAD
    2) CAM
    3) CMM
2) Down selected to eight vendors* and conducted 1:1 presentations in which we:
    1) Introduced PIDs
    2) Set the scope (CAD design – CNC – CMM)
    3) Gave definitions and use case examples
    4) An overview of our then in work efforts with the universities
    5) Read statement that both Lockheed Martin and Northrop Grumman are committed to this effort and we want to see it as an industry standard not a single company solution
    6) Provided a survey for them to fill out and return to us
3) Compile results

* Some vendors offer more than one solutions (eg CAD and CNC) they were only counted once

Vendor Assessment – Outward Facing Results

Category	Description	CAD-A	CAD-B	CAD-C	CNC-A	CMM-A	CMM-B	CMM-C	CMM-D
Importing/ Consuming of PID's	STEP AP242	◑ ↗	◑ ↗	◑ ↗	◑ ↗	◑	◑	◑	◑
	QIF	○	◑	◑ ↗	◑ ↗	◑ ↗	◑ ↗	◑ ↗	● ↗
Generation/ Management/ Maintain	CAD Geometry Level PID's	◑	◑ ↗	◑ ↗	◑	◑ ↗	◑ ↗	◑ ↗	◑ ↗
	PMI Level PID's	◑	◑ ↗	○↗	◑	◑ ↗	◑ ↗	◑ ↗	◑ ↗
	Other PID's	○	◑ ↗	○↗	○	○↗	○↗	◑ ↗	◑ ↗
Exporting/ Linkage to PID's	STEP AP242	○	◑ ↗	◑ ↗	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	QIF	○	◑ ↗	○↗	**N/A**	○↗	◑ ↗	○↗	◑ ↗
Partnership	Aligned / engaged during discussion	**-**	**+++**	**++**	+	**++**	+	**+**	**+++**
	Roadmaps provided	**N**	**Y**	**N**	**N**	**N**	**N**	**N**	**Y**
Overall	Overall readiness for 2028 production	○	◑ ↗	○↗	○↗	○↗	○↗	○↗	◑ ↗

Key: ○ - Not Implemented | ◑ - Partially Implemented | ● - Full Implementation | ↗ - Actively improving

(--) Not interested (-) Somewhat interested (+) Interested (++) Strongly interested (+++) Highly interested

Assessment of software providers indicates active improvement to ensure PID readiness.

Vendor Assessment –Take Aways

Take aways

1) There is interest in the vendors to do PIDs
2) If LM or NG were to target a 2028 program to utilize PID's it would require
    1) It would have to be a program specific goal with specific funding
    2) It would require alignment with specific vendors
    3) It would have several limitations
3) Many of the follow up notes indicated that industry standards are very weak, making it very difficult for vendors to know what universal solution can be obtained. We will be strengthening our relationship standards organizations
4) Open to include more OEM's

Future efforts - standards

Brief this information to the standards communities in Q4 and begin to engage them more as we move to future stages of this effort

- PDES
- MTConnect
- DMSC
- ASME

Engaging software vendors to:

- Now that we have shown what is in the realm of possible, it's time to work with the software vendors to make it 'proper' and incorporate it into the standards.
- Increase participation with the standards organizations
- Drive the standards organizations to update the standards to support PIDs from CAD (STEP AP242) → CAM → in-Process data (MTConnect) → CAI (QIF output).

Expand the LM/NG effort to others:

- LM/NG are working to get approval to bring in more OEMs.
- Date to open invite TBD (Soon)

Thank you for your time today

Questions?