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ROAD TO #IW2025

Feb. 1 February 1 to 4, 2025

Hybrid Event
Barceló Sevilla Renacimiento
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Digital Engineering and System Family Engineering – Innovating at the Speed of Relevance

Webinar 05/09/2024 – INCOSE Product Line Engineering WG

Presenters:

James Teaff, Raytheon, an RTX Business

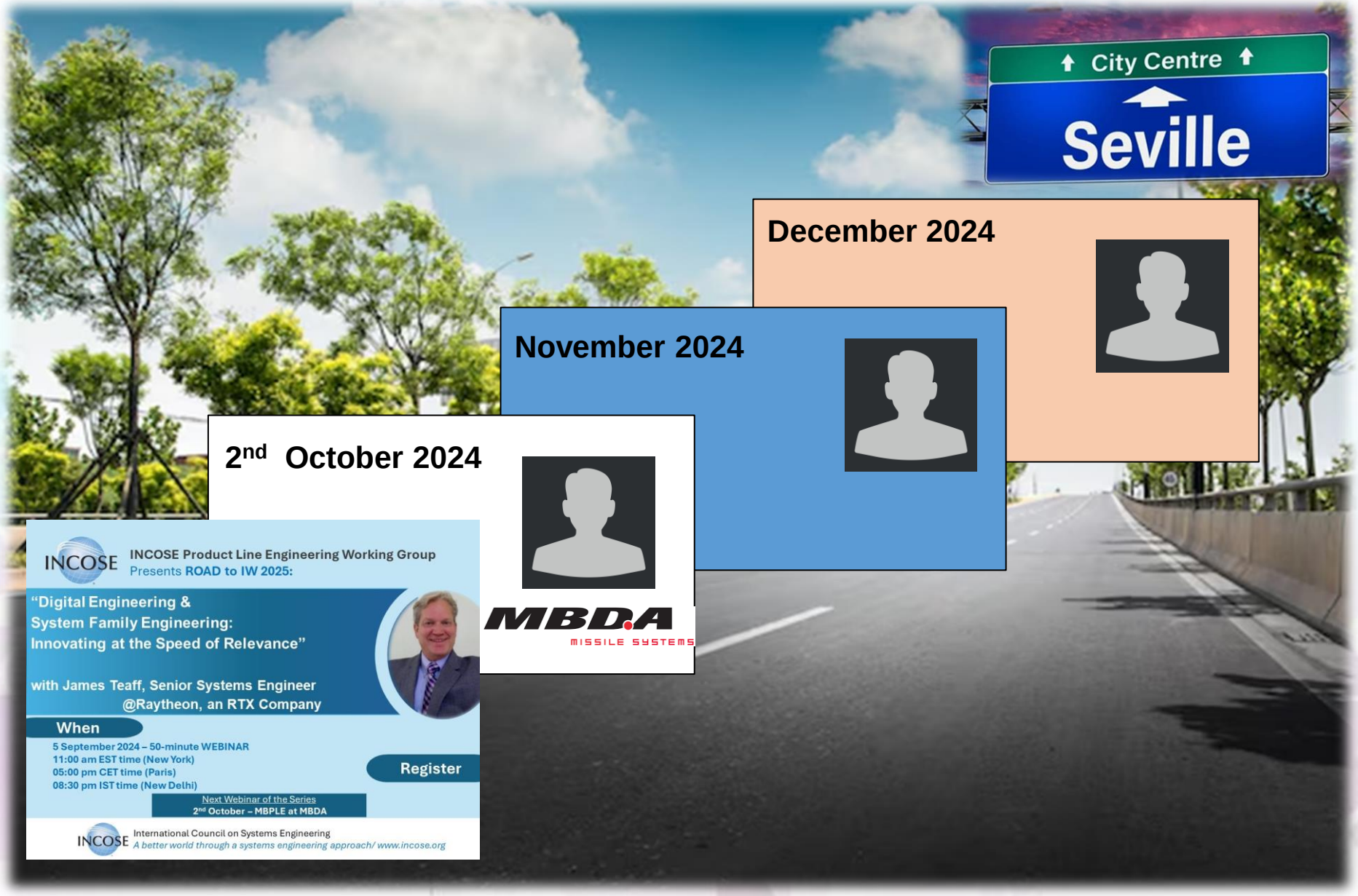
Raytheon Electronic Technical Publication Requests (eTPCR) ID# RIS-21657 Digital Engineering for a System Family

Raytheon
An RTX Business

Introduction

PLE WG Webinar Series– Road to IW 2025

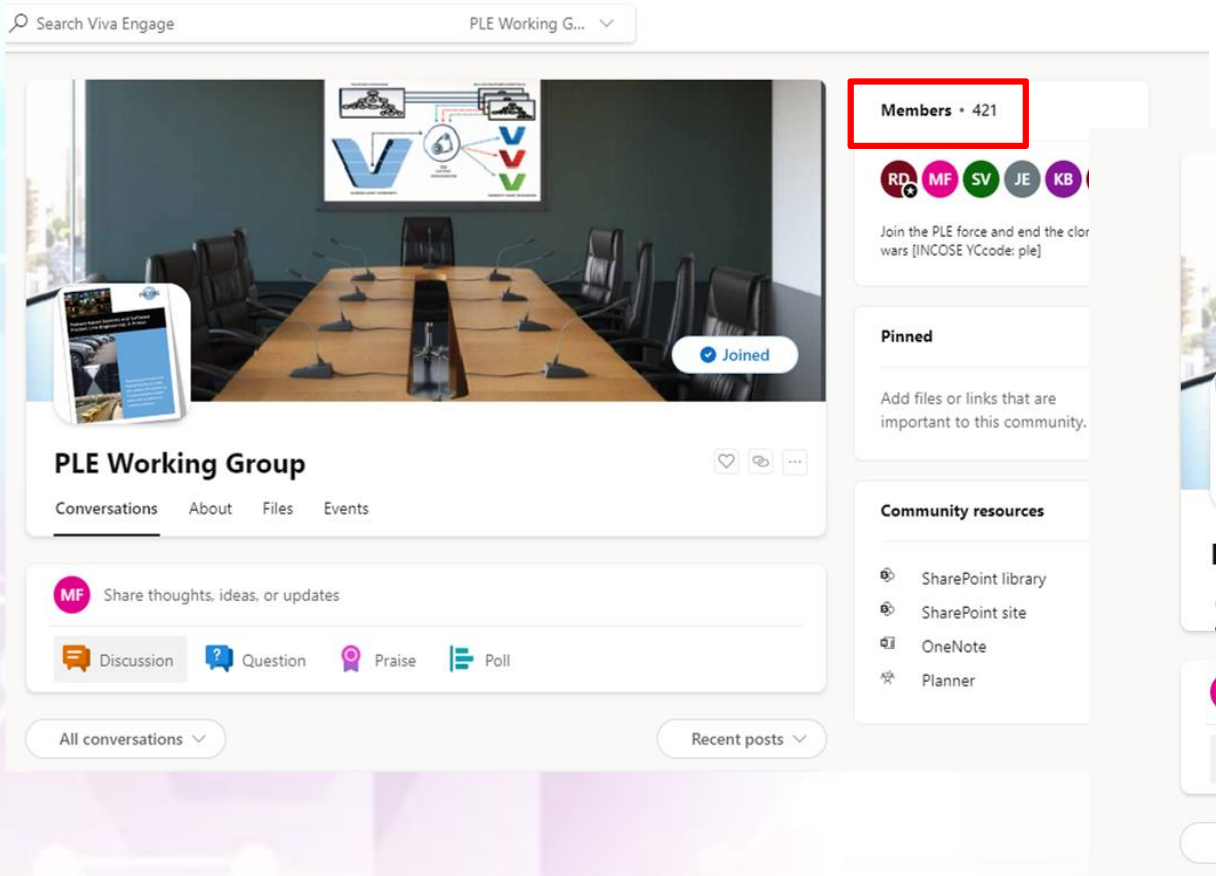
With the **INCOSE International Workshop 2025** in **Seville** swiftly approaching, it seems an opportune moment for the **PLE WG** to initiate **a new series of 4 webinars** that have at the center the adoption of **feature-based Product Line Engineering**.



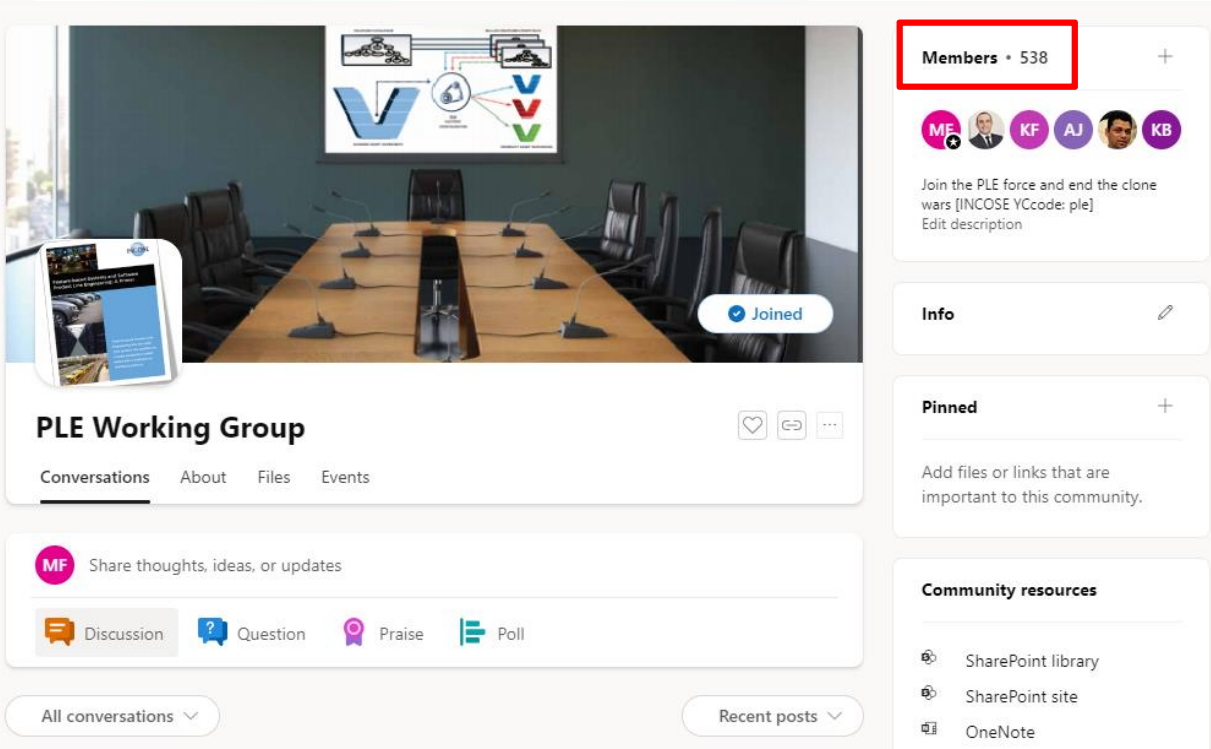
INCOSE PLE WG Community - Growth

+ 28 % members in less than 6 months

March 2024 – 421 members



September 2024 – 538 members



James Teaff

James wrote his first line of software as a professional in the early 80's while working for a small tech startup.

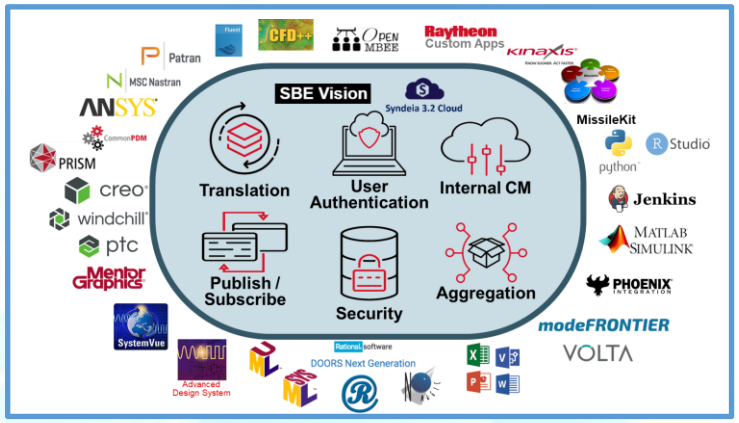
Subsequently over the past several decades he has worked for numerous commercial aerospace and defense contractors across the full system development lifecycle in multiple roles, from R&D principal investigator, to Chief Architect, Engineering Department Manager, Systems Engineering Lead, Requirements Analyst, Scrum Master, Software Engineering Lead, Test Lead, 2nd tier operations & maintenance support, and more.

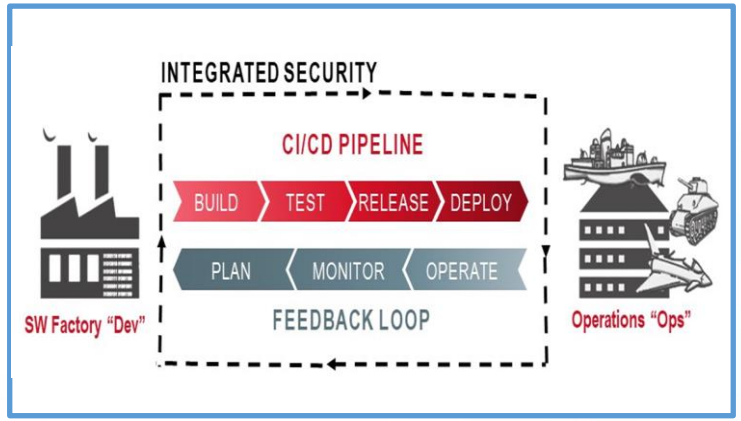
James holds a Master of Engineering in Engineering Management degree from the University of Colorado, a Bachelor of Science degree in Computer Science from Colorado State University, and a graduate certificate in information systems security from Regis University.

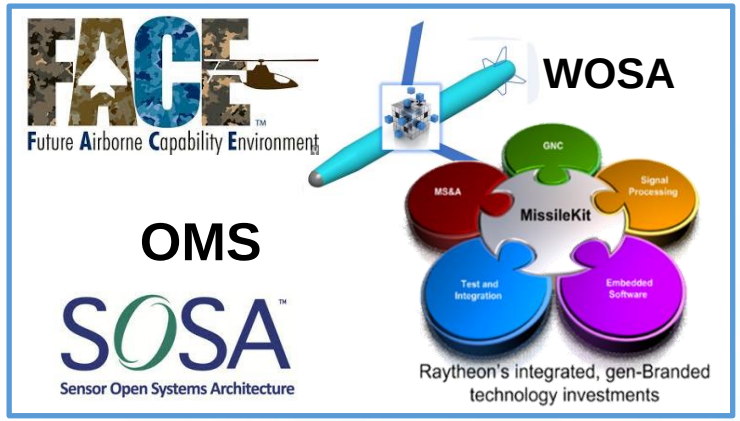
He is an INCOSE Certified Systems Engineering Professional (CSEP), and is an active member of the INCOSE Product Line Engineering International Working Group.

Digital Engineering and System Family Engineering –
Innovating at the Speed of Relevance

Digital Product Development – The DoD "Digital Trinity"







Digital Engineering

An integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal

Agile Software + DevOps

Software development practices and techniques that provide continuous integration and continuous deployment (CI/CD) to support rapid iterative software evolution

MOSA Open Systems Architectures

Standards-based architectures that define modular systems where components can be added, modified, replaced, removed and/or supported by different vendors throughout the life cycle

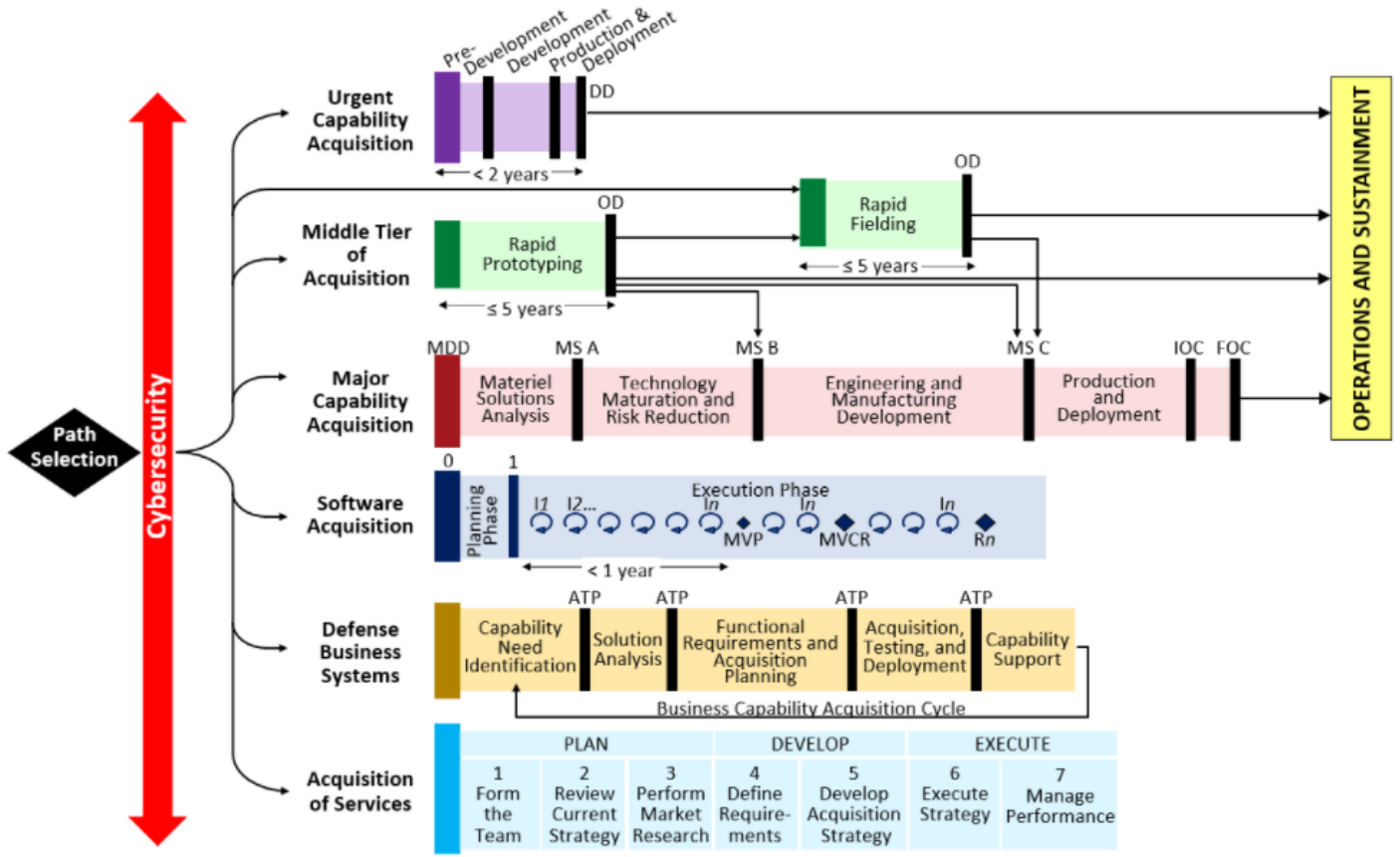
These methods combine to accelerate the delivery of new capabilities to the warfighter at the speed of relevance

Policy and Guidance – DoD Research & Engineering, OUSD(R&E) (cto.mil)

US DoD AAF & Digital Trinity is …

- Modern PLE enables US DoD Adaptive Acquisition Framework (AAF) pathways*
- US DoD telegraphing **preponderance of future acquisitions** will use the Urgent Capability; Middle Tier; and/or Software Acquisition pathway to foster innovation and rapid adaptation
- The **new norm is sets of shorter-duration contracts** to acquire, operate and sustain a family of systems vice a single large, decade-long contract for a single system
- The Digital Trinity vision publications and subsequent directives from the US DoD are **driving a new model for production, operations and sustainment** reflective of commercial industry systems and methods

* See reference below



AAF Pathways Enable Moving – and Innovating - at the Speed of Relevance, reflecting Modern Commercial Industry Systems and Methods

Policy and Guidance – DoD Research & Engineering, OUSD(R&E) (cto.mil)

Engineering of Defense Systems is …

SYSTEMS ENGINEERING & ARCHITECTURE

TECHNICAL HIGHLIGHT: FEBRUARY 2024

ENGINEERING OF DEFENSE SYSTEMS

ENGINEERING DECISIONS

The Department of Defense (DoD) uses data-centric approaches to inform decision making. Modernizing the traditional approach to developing systems (systems engineering) requires digital methodologies, technologies, and practices (digital engineering). This fusion of traditional engineering rigor with digital data strengthens the comprehensive engineering process, as digital models and the underlying critical data advance the Department's ability to design, develop, deliver, operate, and sustain systems.

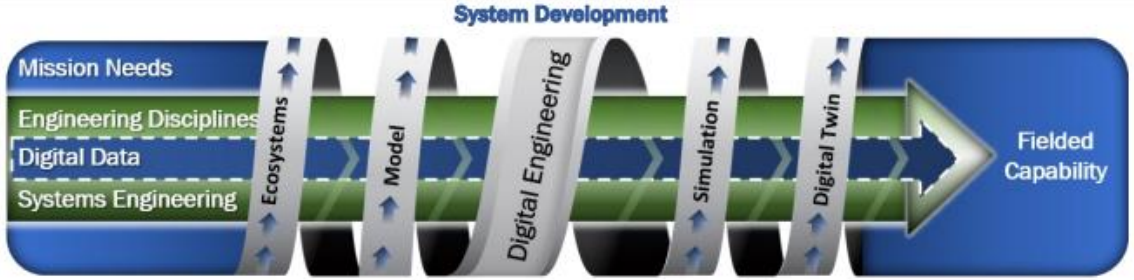


Figure 1. Digital Engineering throughout System Development

Digital engineering does not replace systems engineering but moves the activities into the digital realm.

Digital engineering moves the primary means of communicating system information from documents to digital models and their underlying data.

❖ DATA IS KEY [Policy and Guidance – DoD Research & Engineering, OUSD(R&E) (cto.mil)]

- **Digital Threads**
  - Bidirectionally linked authoritative models and data supporting engineering
- **Digital Twins**
  - Virtual representation of a physical system

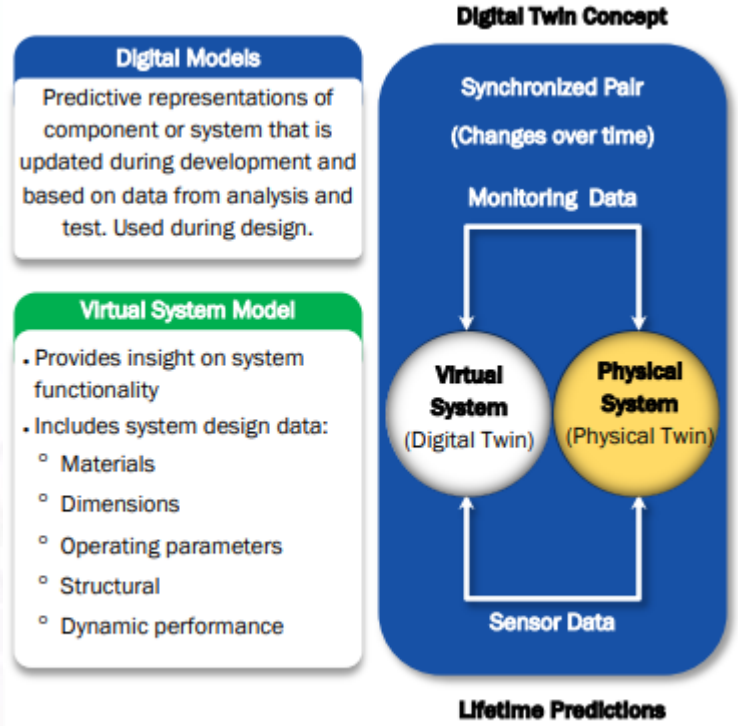
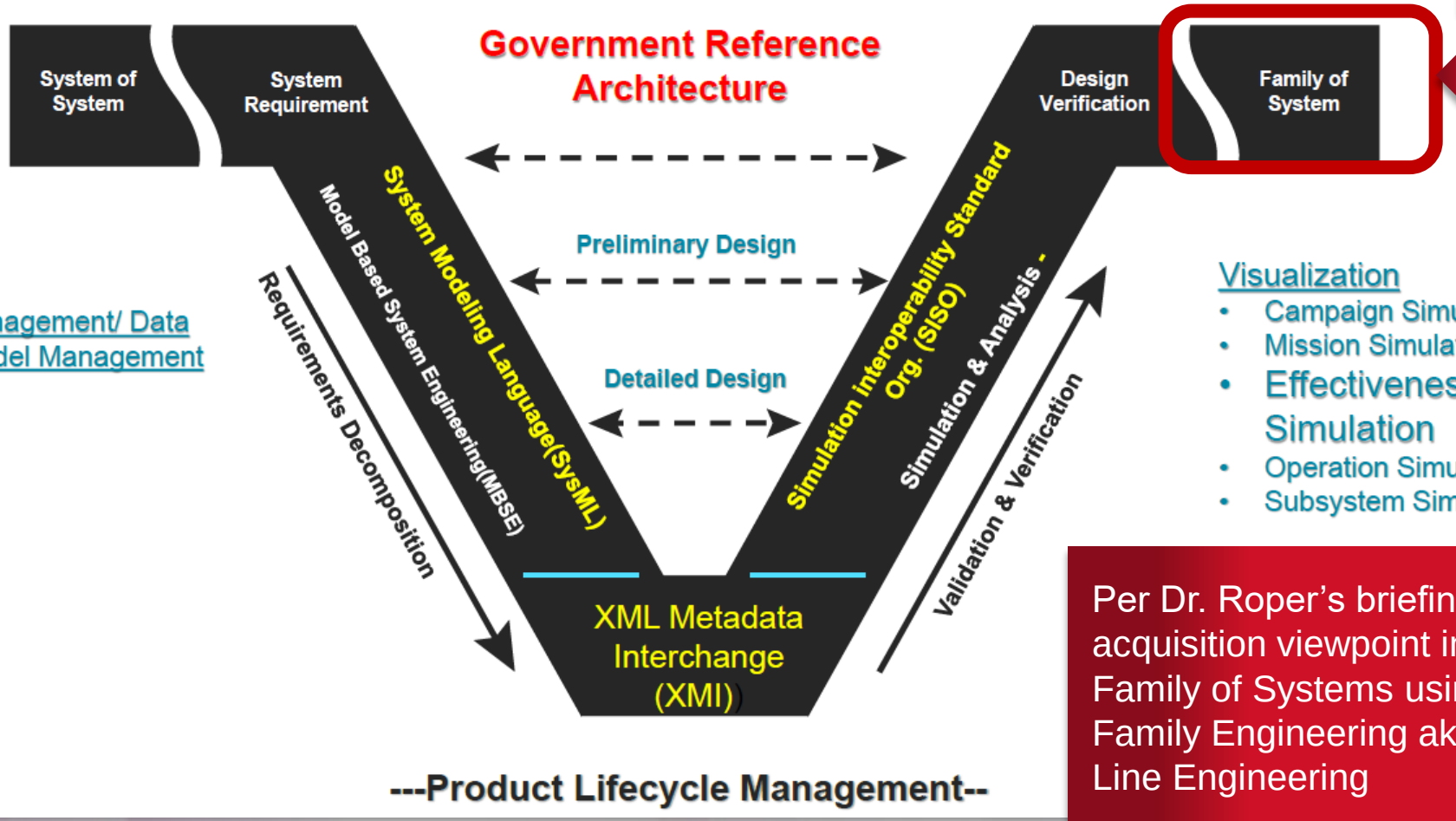


Figure 2. Digital Twin

Digital Trinity for FoS – Add SFE / PLE

Add System Family Engineering



Configuration Management/ Data Management/ Model Management

Visualization
- Campaign Simulation
- Mission Simulation
- Effectiveness Simulation
- Operation Simulation
- Subsystem Simulation

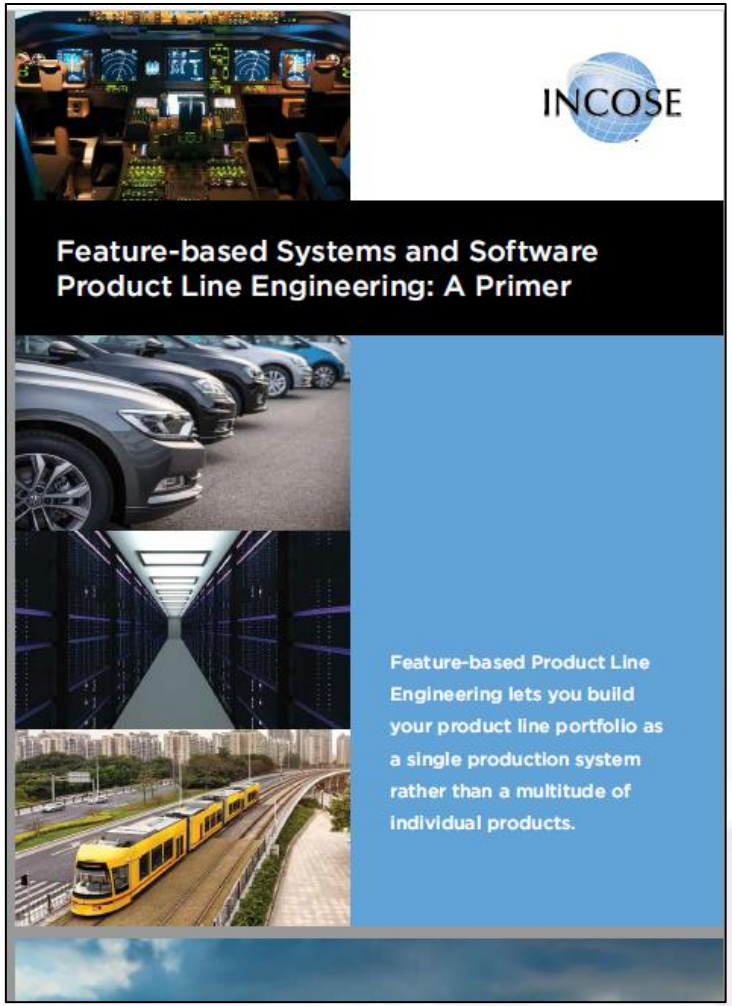
Per Dr. Roper's briefing, US DoD acquisition viewpoint includes Family of Systems using System Family Engineering aka Product Line Engineering

U.S. Air Force Digital Campaign Virtual Industry Exchange Day, Sept 21, 2020. Slide 39.
Dr. Will Roper, Asst Secrety of the Air Force for Acquisition, Technology and Logistics
https://www.afmc.af.mil/Portals/13/AF%20Digital%20Campaign%20Industry%20Exchange%20Day%20Combined%20Slides_Final%20v1.pdf

System Family Engineering / PLE is …

https://www.iso.org/standard/43139.html

- Adds effective, efficient product variation management to digital thread elements
- The **Feature Model becomes the authoritative source of truth (ASoT)** for product line variation definition and management **across the entire digital ecosystem**



How ISO/IEC 26580 FbPLE works …

- A digital asset factory – part of an **Integrated Digital Environment (IDE)** - provides an efficient means to create and maintain a family of products that “share technical DNA”
- Key concepts are:
  - **Feature Catalogue (Feature Models)** that defines the product (variant) features
  - **Supersets of shared Digital Assets**
  - An **automated means to create Product Variants** (the **factory configurator**) composed from shared Digital Assets per an intentional Product Line Architecture (PLA) as defined in a **Bill-of-Features Portfolio**

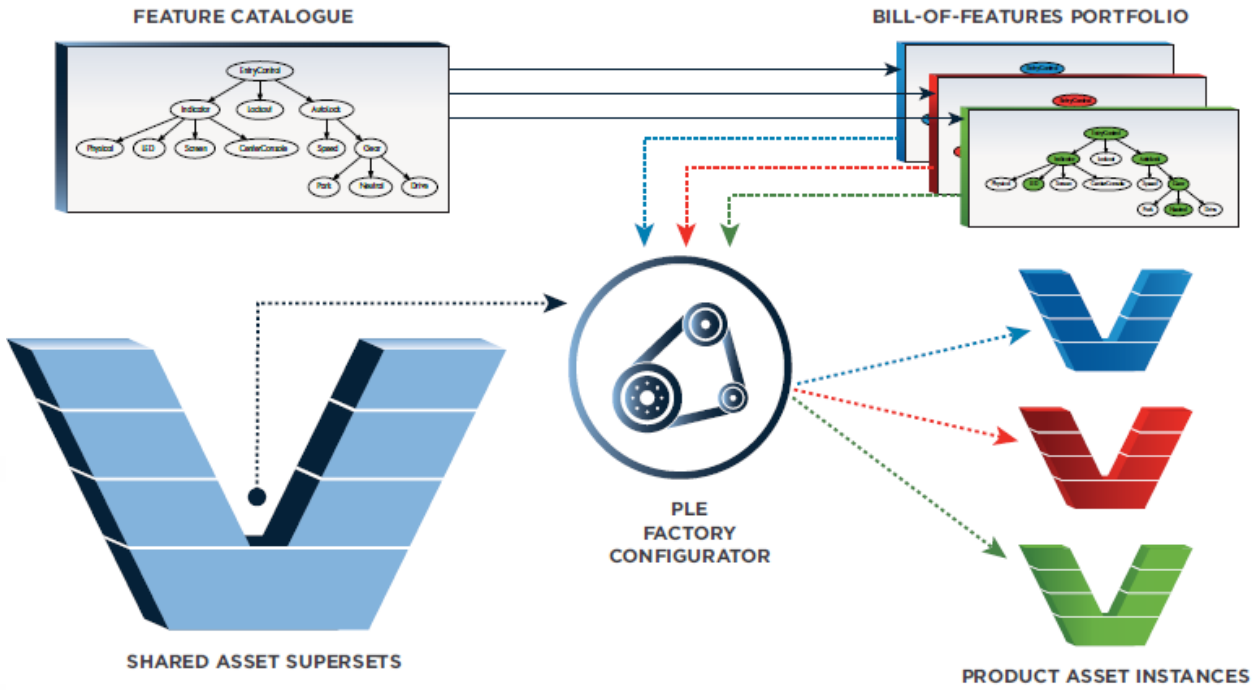


Figure © INCOSE, used with permission

The IDE and continuously evolving shared asset supersets are critical to innovating at the speed of relevance

- **Automated** Product Variant Production, Operations and Maintenance **using Product Rules** to verify product variants, prevent quality escapes, enforce EX/IM laws, and similar

https://www.iso.org/standard/43139.html

FbPLE Foundationally Uses Features as the Common Language

ISO/IEC 26580 FbPLE uses *features* as the *lingua franca* – common language – to describe products

- A Feature is an **abstract description of the form, fit, & function** of system elements
- **User: "I need …"**
- **Eliminates the communication "impedance mismatch"** between user/warfighter, purchasing/acquisition, systems engineering, software engineering, test, certification, …
- **Features can be invariant (common); or variant (different for each fielded systems)***
- **Feature-based engineering is a mature, widely adopted approach**:
- *Product line engineering*
- *Agile software development*
- *Manufacturing*

https://www.iso.org/standard/43139.html

Feature-Oriented Domain Analysis (FODA) Feasibility Study

Kyo C. Kang
Sholom G. Cohen
James A. Hess
William E. Novak
A. Spencer Peterson

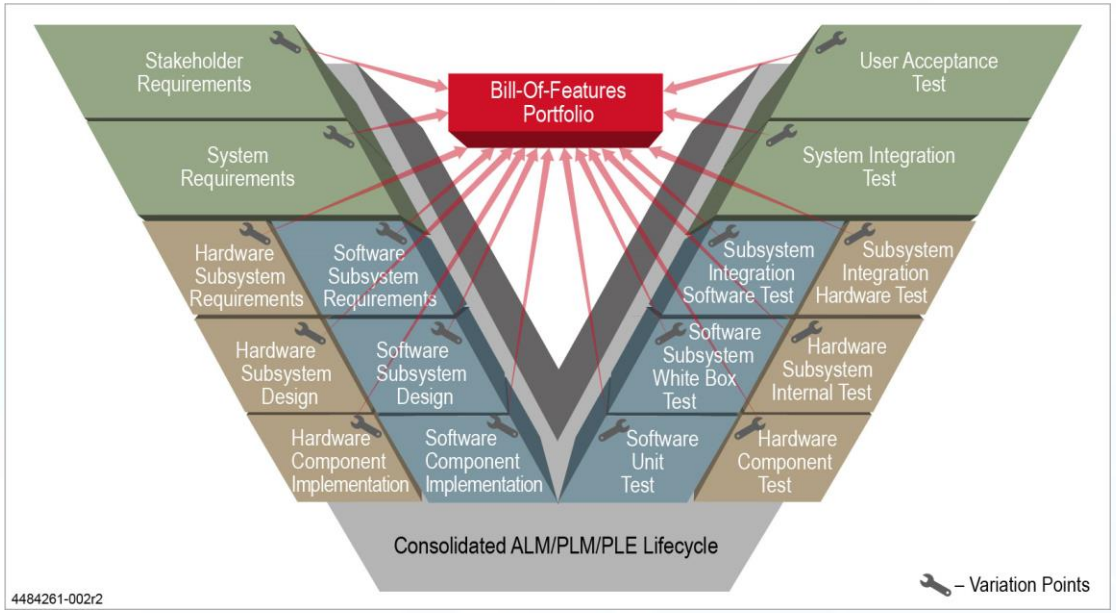
November 1990

Software Engineering Institute
Carnegie Mellon University
Pittsburgh, Pennsylvania 15213

- **Behavioral** Features
- **Structural** Features

** ISO/IEC product feature = a variant product feature in our lexicon*

ISO/IEC 26580 FbPLE High Level Iterative Process



System Family of Interest (SFoI)

Perform Feature-Oriented Scope, Commonality and Variability Analysis

Create product (variant) Feature Models

System of Interest (SoI)

Capture Stakeholder Requirements

Synthesize System Requirements

Create System Models

Create Architecture Models

Create Hardware Design Models

Create Software Design Models

Fabricate Software

Acquire Software

Simulate System

Fabricate Hardware

Acquire Hardware

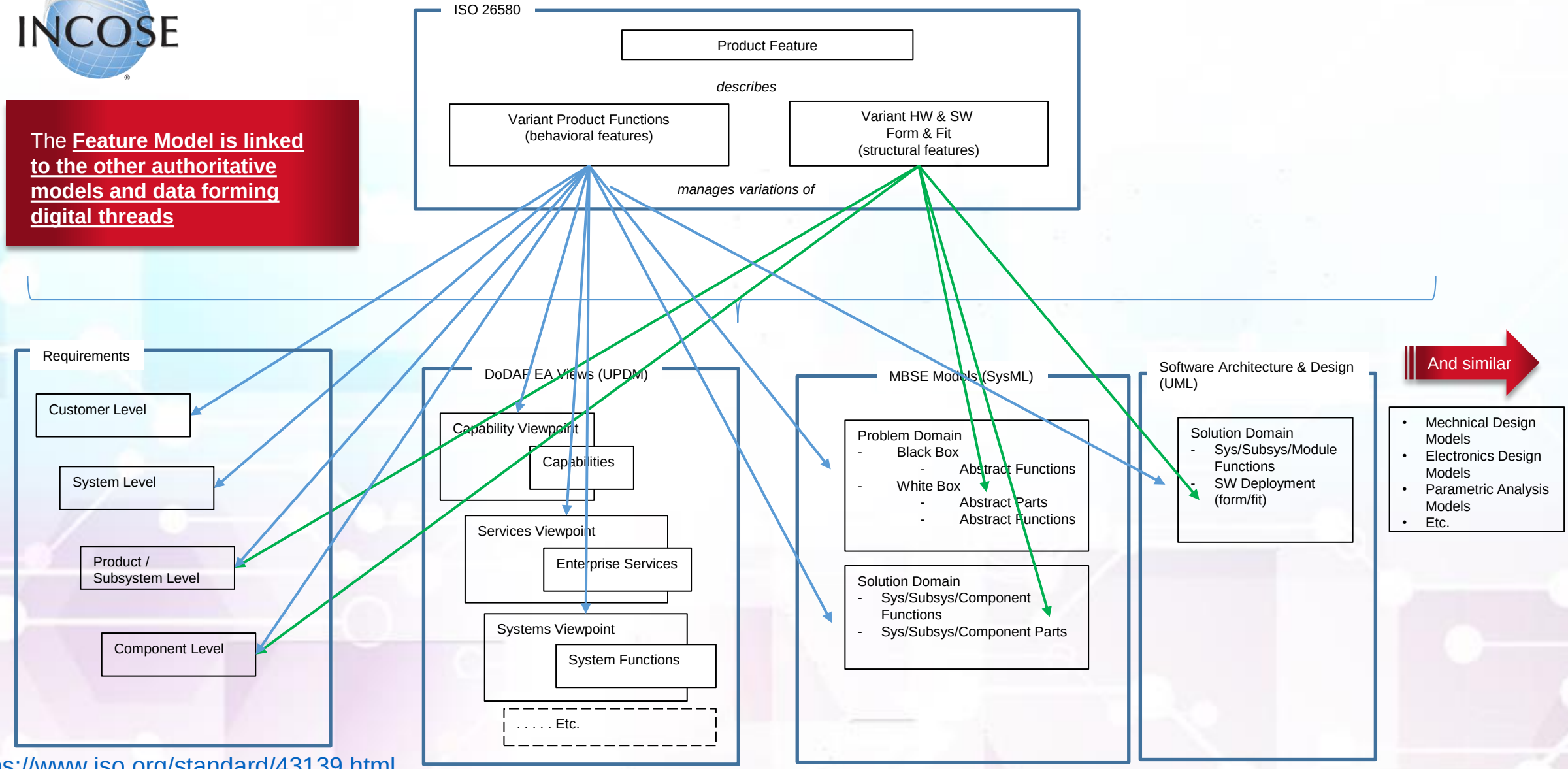
Etc.

- Feature Model + Feature Profiles + Bill-of-Features Portfolio efficiently **manage variation** across the full lifecycle for **all categories of digital assets for the SFoI**

https://www.iso.org/standard/43139.html

Digital Threads = Bidirectionally Linked Models

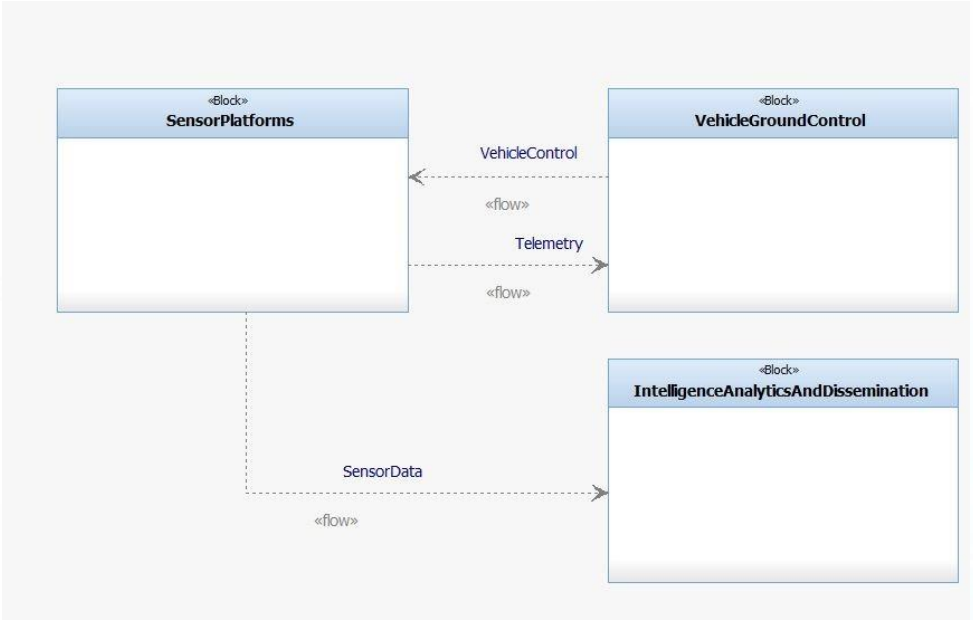
The **Feature Model is linked to the other authoritative models and data forming digital threads**



https://www.iso.org/standard/43139.html

Hypothetical SFoI

- Let's apply FbPLE + DE + Dev*Ops + MOSA OSAs to a hypothetical intelligence gathering system (H-IGS) as depicted, concentrating on the FbPLE aspects
- Today's cyber-physical systems must survive in a constantly changing threat environment
- Cybersecurity controls and cyber resiliency capabilities require continuous delivery to meet this challenge
  - EX/IM requires product feature variations
  - Evolving threats require product feature variations
  - Technology advancements require product feature variations
  - Different price points require product feature variations
  - And so on …
- Using a rule base as an integral part of a systems and software product line engineering factory enables automated, continuous verification & validation of the cybersecurity controls and cyber resiliency features ensuring the system continues to function even under extremely disruptive conditions

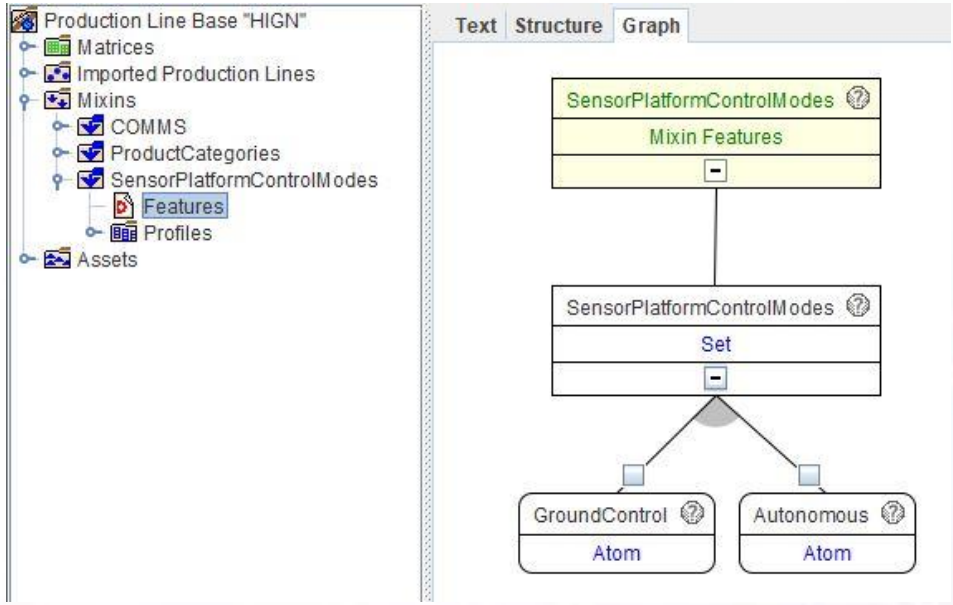


"The key to FbPLE is automation through a product line engineering factory. At the factory's center is a rule base used to verify and validate each system variant created by the factory. A rule base is a specialized knowledge base obtained from subject matter experts and digitized as a set of rules. A product rule is a system constraint represented in a rule base as an assertion. Each assertion is a Boolean expression - a true or false expression."

Teaff, J. (2020), "Rule-based Verification of System Security using Feature-Based Product Line Engineering", Insight Magazine, Volume 23, Issue 3, September 2020, (http://onlinelibrary.wiley.com)

Feature-Oriented Scope, Commonality and Variability Analysis

- The H-IGN product portfolio supports three primary variations:
  - Small area of interest (AOI): line of sight UxV control and one analyst such as covering a city block
  - Medium AOI: less than 200 square miles and up to five analysts such as covering a city
  - Large AOI: less than 125,000 square miles and up to twenty analysts
- FO-SCV analysis begins with eliciting what product features are in scope for the product line, followed by determining what features can be common (invariant); and what features need to be variant (different form/fit/function)
- Variant product features are modeled forming the ASoT for variation for the SFoI



H-IGN Sensor Platform Control Modes Product Feature Model

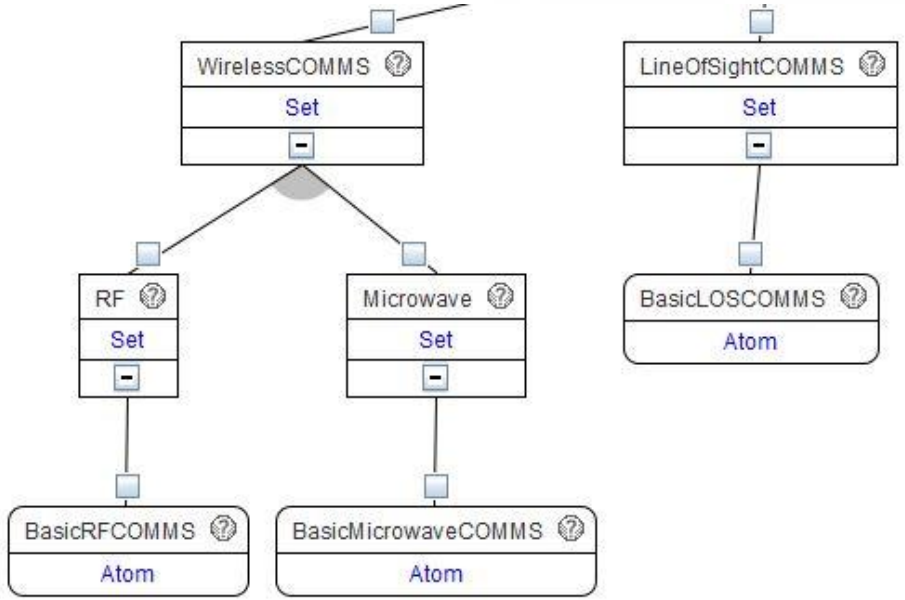
The H-IGN system supports the following sensor platform control options:
- Continuous active ground control
- Autonomous vehicle control

Teaff, J. (2020), "Rule-based Verification of System Security using Feature-Based Product Line Engineering", Insight Magazine, Volume 23, Issue 3, September 2020, (http://onlinelibrary.wiley.com)

The Factory Rule Base

"Creating and using a rule base begins with analyzing the cyber-attack surface for each system variant in the product portfolio. Systems engineers then design invariant and variant system capabilities for each fielded system addressing the identified attack vectors. The factory uses product rules to automatically ensure each output product configuration is secure, delivery after delivery to the field."

- The cyber-attack surface analysis for the H-IGN system identifies the ground control to UxV communications system (COMMS) as an attack vector. Potential attacks include:
  - Passive data interception
  - Covert data modification
  - COMMS disruption
- Product features are modeled based on the attack vector
- Product rules are digitized ensuring inclusion / exclusion of the requisite product features
  - EX/IM, ITAR, operational environment considerations, fielded product variant capabilities, and similar



Subset of H-IGN COMMS Variant Product Features

"All product variants shall encrypt data", and "RF COMMS shall use a frequency hopping algorithm"

```
Assert ((COMMS.COMMSTypes.WirelessCOMMS.RF >=
{BasicRFCOMMS}) REQUIRES (COMMS.COMMSCybersecurity.
EncryptionAlgorithm == {EncryptionAlgo_Alpha}));
Assert ((COMMS.COMMSTypes.WirelessCOMMS.RF >=
{BasicRFCOMMS})
REQUIRES (COMMS.COMMSCybersecurity.
FrequencyHoppingAlgorithm == {FreqHopAlgo_Bravo}));
```

Teaff, J. (2020), "Rule-based Verification of System Security using Feature-Based Product Line Engineering", Insight Magazine, Volume 23, Issue 3, September 2020, (http://onlinelibrary.wiley.com)

The Digital Asset with Variation Points

- The final step is to create digital assets, add variation points - planned for, controlled points of variability in assets to accommodate a specific operational context – and create the logic for the PLE Factory Configurator to exercise the variation points; that is, to configure the assets using one or more feature profiles in a bill-of-features

```
When (true)
  Select "NonsensicalCOMMSModule.java"
  {
    If (NOT (COMMS.COMMSTypes.WiredCOMMS >= {BasicWiredCOMMS})) {
      DeleteBlock Java "FooTag";
    }
    If (NOT (COMMS.COMMSTypes.WiredCOMMS >= {EnhancedWiredCOMMS})) {
      DeleteBlock Java “BarTag";
    }
    StripBlockDelimiters;
  }
```

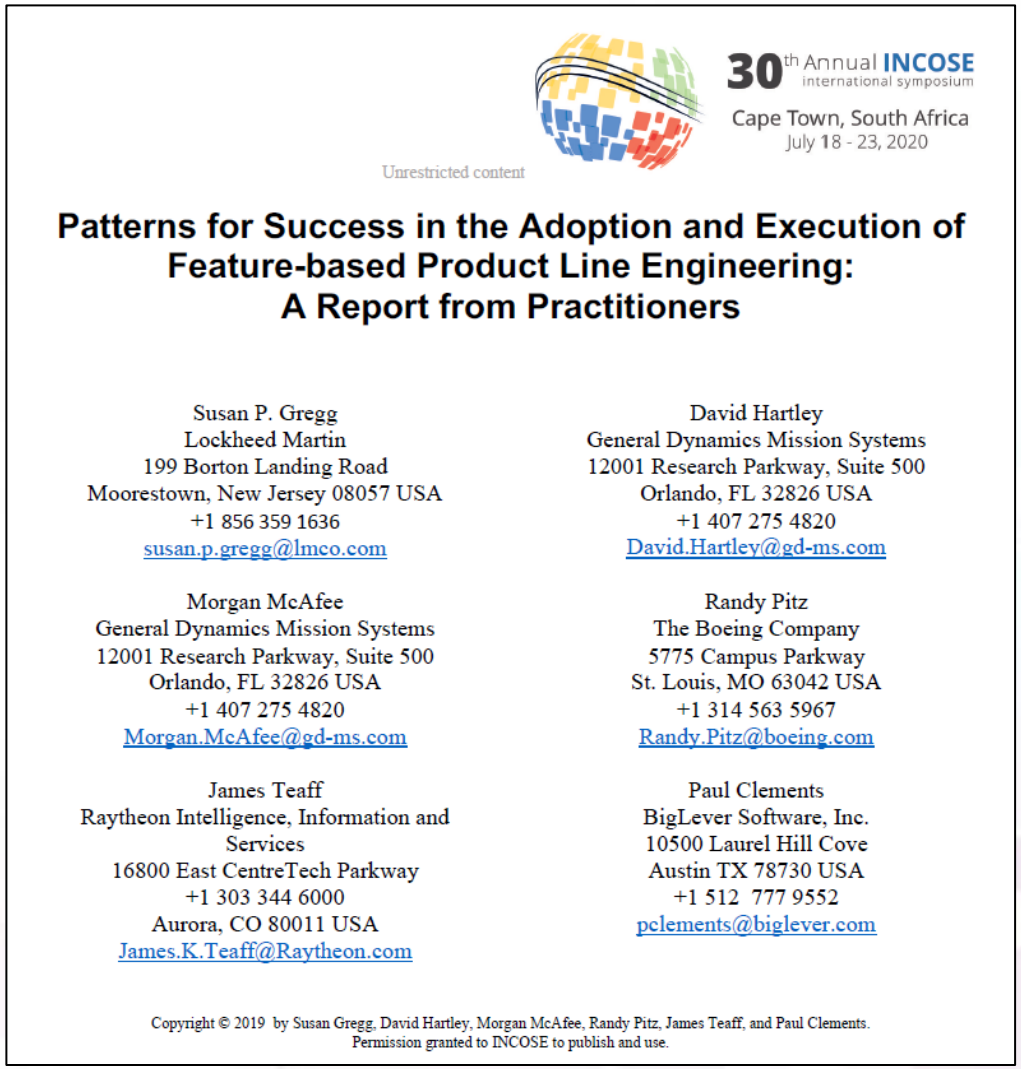
Note: extremely trivial example - typically, you would instrument digital assets with much more industrial-strength variation points based on the product feature models, including injecting strings, floats, integers, … when projecting the digital assets to the staging areas

```
1  package com.Raytheon;
2
3  public class NonsensicalCOMMSModule {
4
5      public boolean doNothing () {
6
7          ///* BeginGearsBlock Java FooTag
8          System.out.println("Foo");
9          ///* EndGearsBlock Java FooTag
10
11         ///* BeginGearsBlock Java BarTag
12         System.out.println("Bar");
13         ///* EndGearsBlock Java BarTag
14
15         return true;
16
17     }
18
19 }
20
```

Adoption

Solutions

- Methods to enable secure & efficient production and maintenance where the system comprises unclassified and classified - at varying levels – content
- MBSE for SFoI's best practices = MBPLE
- Capability-rich, increasingly integrated tool vendor support (IDE)
- Methods for verification and validation where human safety is involved; and/or where the fielded system cannot be easily maintained e.g., a satellite in orbit
- Over two decades of research at the Software Engineering Institute (SEI)
- **Not to mention ongoing research at the INCOSE PLE IWG**
- And more …



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Patterns for Success in the Adoption and Execution of Feature-based Product Line Engineering: A Report from Practitioners

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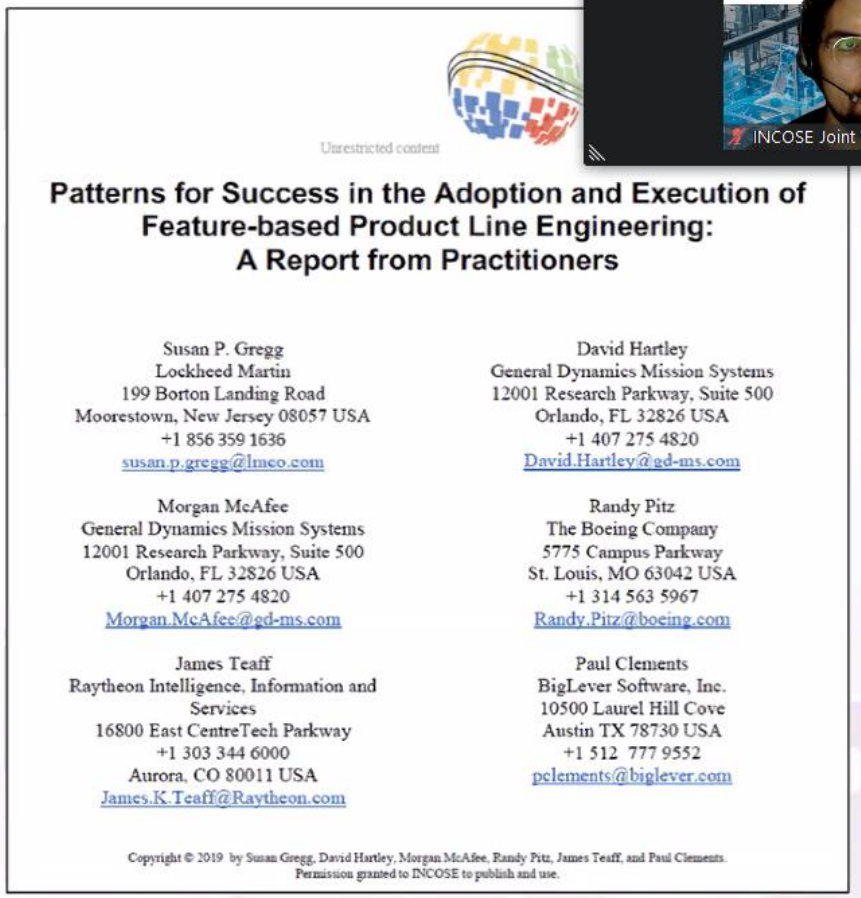

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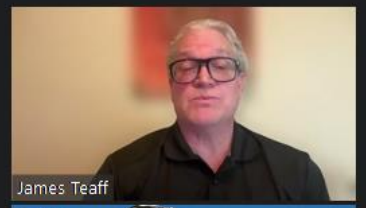

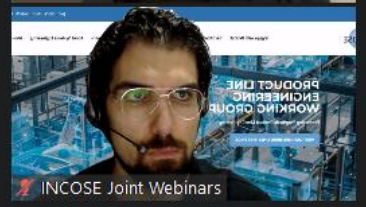

Thank You

Question Time!

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Abstract

- Starting October of 2020 Dr. Will Roper, then Assistant Secretary of the US Air Force for Acquisition, Technology, and Logistics, published a set of whitepapers describing the use of a digital trinity of methods to transform the U.S. DoD acquisition process to meet the needs of today's warfighter. Combined with DoD Instruction 5000.02 Operation of the Adaptive Acquisition Framework (AAF), published in January of 2020, and related memorandum, the DoD established the requirement for industry, academia, standards consortia, and similar to innovate at the speed of relevance. Originally described as digital engineering + agile software + open system architecture, the digital trinity is now more commonly described as digital engineering (DE) + development-operations "plus" (Dev*Ops) + modular open systems approach (MOSA) open system architectures (OSAs). Initially focused on a system of interest (SoI), subsequent briefings from the DoD and analysis by industry recognized the requirement to expand the focus of the digital trinity to a system family of interest (SFoI). Modern product line engineering (PLE) as codified in the ISO/IEC 26580:2021 standard establishes a system and method that augments the digital trinity for SFoIs, enabling the DoD and defense contractors to innovate at the speed of relevance. This presentation and accompanying whitepaper describes the augmented system and method of PLE + DE + Dev*Ops + MOSA OSAs – what it is, how it works, and its value / return on investment (ROI); and then demonstrates its application using a hypothetical intelligence gathering and analytics SFoI. This paper also describes common challenges for using the product line engineering + digital trinity system method, with recommendations for overcoming the challenges. Challenges addressed include funding SFoI's conformant to the Federal Acquisition Regulation (FAR) and the Other Transaction Authority (OTA) legal instrument; and forecasting value / ROI using an augmented version of the Software Engineering Institutes' Structured Intuitive Model for Product Line Economics: SIMPLE++.