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## Feature-based Product Line Engineering in Aerospace and Defense

NDIA 2021 Virtual Systems & Mission Engineering Conference  
December 6-8, 2021

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Charles Krueger, PhD, CEO  
BigLever

**onePLE**

Approved for Public Release



## ISO/IEC 26580

- On April 20, 2021, it became official:
  - ISO/IEC 26580, “Methods and Tools for the Feature-based Approach to Software and Systems Product Line Engineering”, was published as an international standard
  - <https://www.iso.org/standard/43139.html>
- For the aerospace and defense industry:
  - this powerful engineering approach, created to deliver unprecedented cost avoidance and quality, can now be readily and unambiguously mandated in RFPs and contracts,
  - which can then be unambiguously provided by contractors,
  - leveraging 26580 as the authoritative definition from the international engineering community

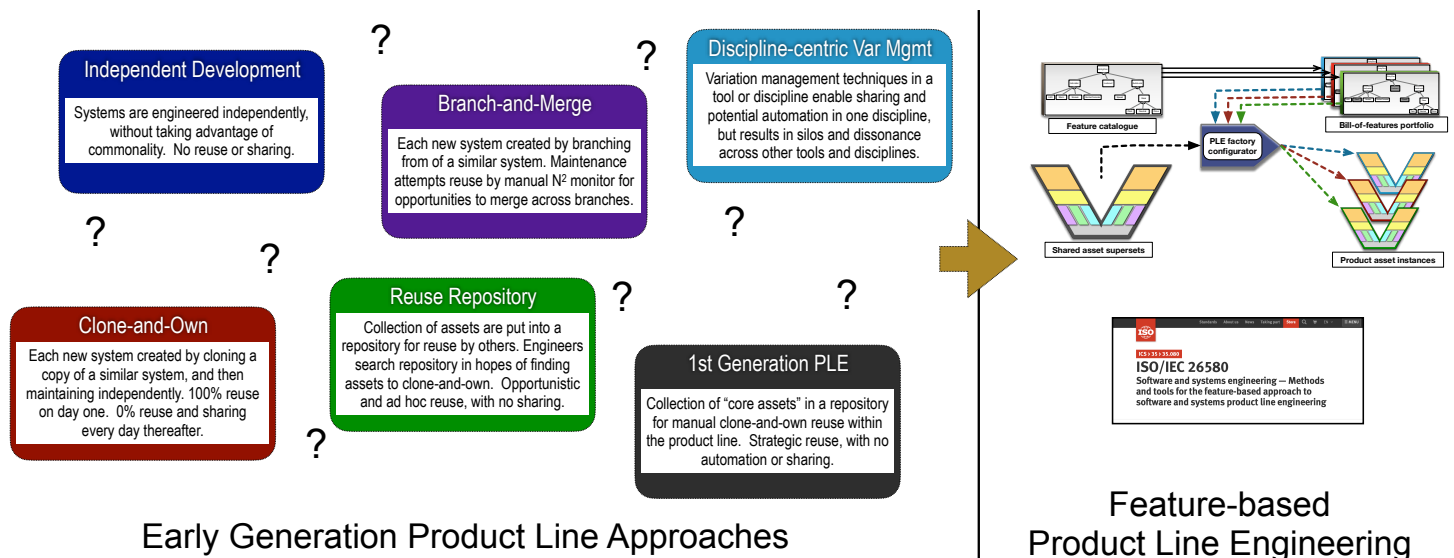
The screenshot shows the ISO website interface for the standard ISO/IEC 26580:2021. At the top, there are navigation links for Standards, About us, News, Taking part, Store, and a search icon. The main heading is 'ISO/IEC 26580:2021 Software and systems engineering — Methods and tools for the feature-based approach to software and systems product line engineering'. Below this, there is a 'BUY THIS STANDARD' section with options for 'FORMAT' (PDF + EPUB) and 'LANGUAGE' (English). The price is listed as CHF 178. An 'ABSTRACT' section is also visible, providing a summary of the document's content.

## Business Context for PLE: Variation is the #1 driver of complexity

- *“The top driver of operational complexity in complex engineering organizations, as identified by surveys of hundreds of business leaders, is the number of product and system configurations engineered, manufactured, deployed, and sustained.”*
  - Michelle Boucher, VP of Research for Engineering Practices at Tech-Clarity, an independent research and analyst firm. Michelle has spent over 20 years in various roles in engineering, marketing, management, and as an analyst. She has benchmarked over 7000 product development professionals and published over 90 reports on product development best practices. She focuses on helping companies manage the complexity of today’s products, markets, design environments, and value chains to achieve higher profitability.
  - Source: “Why Should Business Leaders Care About PLE?,” Momentum 2021 presentation, May 2021.
  - <https://tech-clarity.com/about/michelle-boucher>



## Engineering Advancement from Early Generation Approaches



# Product Line Engineering (PLE) Defined

## ISO 26580 Methods and Tools for Feature-based PLE

### Product Line:

A family of similar products or systems with variations in features.

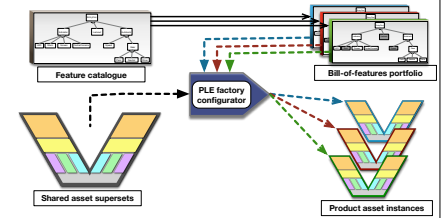
*Product lines are ubiquitous — virtually all products and systems are built in the context of a family.*



International Organization for Standardization

### Product Line Engineering:

the engineering of a product line using *shared engineering assets, a managed catalog of features, and an automated means of production...*



→ taking advantage of the **commonality** shared across the family

→ efficiently and systematically managing the **variation** among the products or systems

# Feature-based Product Line Engineering

## ISO 26580 Methods and Tools for Feature-based PLE

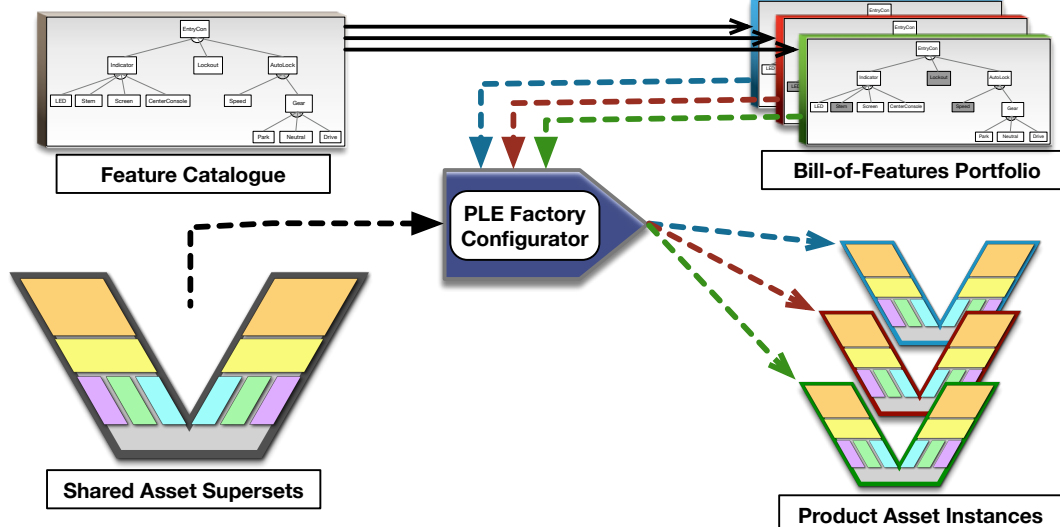


Figure from ISO/IEC 26580  
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<https://www.iso.org/standard/43139.html>

## The ISO/IEC 26580 standard is new, but Feature-based PLE is not

- Although the standard has just been finalized, Feature-based PLE has been in commercial practice in the A&D sector for nearly two decades
  - compiling hundreds of millions of dollars in cost avoidance each and every year
- The approach is being adopted or is already in widespread use by most of the top ten US defense contractors
- Feature-based PLE has earned its stripes by rising to the practicalities and hard challenges that are emblematic of the A&D sector



AEGIS Weapon System for US and International Navies	Live Training Transformation: US Army, Air Force, Marines. Plus enterprise initiative.	One of the largest and most complex product lines, comprising millions of instances per year	Rapidly growing and evolving portfolio of the world's most advanced missile systems	Helicopter engines for all configurations of the new US Army Future Vertical Lift (FVL) program
High cost of old approach threatened loss of entire contract	Innovative low-cost solution essential to win and retain major contracts	Significant challenges to provide suppliers with a family of complex specs for electronic controller unit families	Traditional methods of creating and testing prototypes are too slow, imprecise, expensive to meet mission demands	Demand to maximize sharing and reuse to prevent multiplicative costs for flight certification

### Feature-based PLE Results with BigLever

Turned an at-risk program into an enthusiastic long-term relationship by eliminating low-value redundant effort	Grew a \$2B+ business from scratch with the US DoD. Delivering 3x more capability within budget, to the delight of the customer	Digital transformation to a digital supply chain by applying PLE to MBSE	Using Feature-based PLE to proliferate best candidate simulations to find optimal solution within a trade space	Using a single Feature-based PLE Factory with a single collection of shared engineering assets for the full engineering lifecycle
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## “Change is good. You go first.”

- When it comes to Organizational Change, technology is easy and people are hard
- “Feature-based PLE sounds great, but we’re different — it won’t work here...”
- Engineering organizations are justifiably risk-averse



## Lowering the risk of organizational change by elevating Product Line Engineering to a standard practice in the industry

**ISO/IEC 26580**  
Software and systems engineering — Methods and tools for the feature-based approach to software and systems product line engineering

GENERAL INFORMATION  
Status: © Under development Publication date: 2021-04  
Edition: 1  
Technical Committee: ISO/IEC JTC 1/SC 7 Software and systems engineering  
ICS: 35.040 Software

**SUSTAINABLE GOALS**  
This standard contributes to the following Sustainable Development Goal:

**OMG SysML v2**  
The next generation Systems Modeling Language

Responses to RFP Date: 4 November 2019

**INCOSE**

**Feature-based Systems and Software Product Line Engineering: A Primer**

Feature-based Product Line Engineering lets you build your product line portfolio as a single production system rather than a multitude of individual products.

**SEBOK** GUIDE TO THE SYSTEMS ENGINEERING BODY OF KNOWLEDGE

Version page: Final View source View history PDF Export Search Global

**Guide to the Systems Engineering Body of Knowledge (SEBOK)**  
Guides to the Systems Engineering Body of Knowledge (SEBOK)

The SEBOK provides a compendium of the key knowledge sources and references used. It is a living product, awaiting community input continuously, with regular updates. Systems engineering is an interdisciplinary approach and means to enable the full problem discovery and formulation, solution selection and realization, and operational solutions in the management of multiple interventions in commercial or public or other contexts as a discipline of systems engineering, placed in historical context, and

Welcome to SEBOK v. 2.2  
On behalf of the INCOSE System Board, the INCOSE Governing Board, and sponsor version 2.2. This version was released on 10 May 2020 and reflects the continuing

What's new in v. 2.2?  
For a summary of the changes made for v. 2.2 see the Letter from the Editor. See a Release History for a full description of the current and all previous SEBOK versions.

About the SEBOK  
Systems engineering has its roots in the fundamental, principles, and models of its sciences, and associated management and engineering sciences. It is applied through systems engineering processes within a managed life cycle working with a number of engineering, and societal disciplines. While traditionally applied to product development systems, its systems engineering is a collaborative approach, working with other disciplines and structures at individual, team, and organizational levels.

Starting from this base view of the scope of knowledge relevant to SE, the SEBOK:

- Social Systems: Science Knowledge
- People & People's Competence
- Education & Training Knowledge

**INCOSE**

**SYSTEMS ENGINEERING HANDBOOK**  
A GUIDE FOR SYSTEM LIFE CYCLE PROCESSES AND ACTIVITIES

FOURTH EDITION

WILEY

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**A WORLD IN MOTION**  
Systems Engineering Yearbook 2021

WILEY

# Feature-based PLE in a multi-contract funding context

- In A&D, sharing often needs to occur across programs, contracts, and customers.
- Can that happen? It can.
- Defense companies have worked out methods to pay for activities that benefit more than one program, using an approach that is compliant with acquisition regulations.

August 31, 2021



## Funding the PLE Factory in a Multi-Customer Contract-Based PLE Organization

Report #20170725014

### Funding the PLE Factory in a Multi-Customer Contract-Based PLE Organization

Feature-based automation-centered product line engineering employs the concept of a PLE factory, which is development for any of the products in a product line. Individual products are produced by automatically configuring shared assets into the hardware for a product. An organization employing this paradigm is a contract-based PLE organization. A contract-based PLE organization must answer the question: Who pays for the work that goes on inside the factory? The answer can be surprisingly complex, involving issues of security, regulatory compliance, and protection of intellectual property of both the PLE organization and the customer. This report offers a method for answering the question, "Who pays for the activities in the PLE Factory?"

#### 1. Purpose

A product line organization (PLO) used to carry out a variety of tasks associated with the creation, development, delivery, and evolution of products in a product line. The product line organization needs to establish processes that capture work enabling change readiness to which everyone working in the PLE Factory can change their efforts. These processes must ensure the ability of funding in the emergence of the funding in a way that is, repeatable, and compliant with applicable rules and regulations.

#### 2. Background

In this report we assume that the PLE organization has adopted a structure similar to the one shown in Figure 1. The PLE factory is shown on the left, the shared assets are represented as the system engineering "V" inside at the bottom. The configuration business function-based product development (BFD) of Feature-based Product Development (FBPD) that composed the product. Product lines, who receive requests from the PLE organization, will define products, and working with customers, who define on the right (BFD), all development happens inside the PLE Factory.

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**ABSTRACT**  
Feature-based Product Line Engineering is a well-defined, repeatable, automation-centered PLE method that is allowing even improvements to time, cost, and quality. An organization intent on adopting this PLE can use the description for their product line of products that needs to be developed through the program model and that do not have to be developed in a new way. This article describes an organizational structure for Feature-based PLE based on the factory concept. It structures the factory so that it can be used by other development disciplines that are aware of Feature-based PLE. It also describes how to build system engineering roles carry out traditional system engineering tasks, but with slight PLE support extensions. Finally, we will explore why these changes are necessary.

#### INTRODUCTION

Feature-based product line engineering (FBPD) is a well-defined, repeatable, automation-centered PLE method that is allowing even improvements to time, cost, and quality. An organization intent on adopting this PLE can use the description for their product line of products that needs to be developed through the program model and that do not have to be developed in a new way. This article describes an organizational structure for Feature-based PLE based on the factory concept. It structures the factory so that it can be used by other development disciplines that are aware of Feature-based PLE. It also describes how to build system engineering roles carry out traditional system engineering tasks, but with slight PLE support extensions. Finally, we will explore why these changes are necessary.

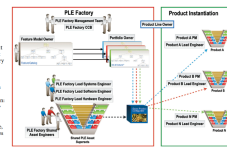


Figure 1. PLE organizational structure

Inc. Confidential

1

# Feature-based PLE and export control compliance

- A product line may have members destined for sale in countries where ITAR or export control restrictions apply.
- Lockheed Martin pioneered a PLE method to ensure that no product contains any content that is not allowed to be exported.

## A PLE-Based Auditing Method for Protecting Restricted Content in Derived Products

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#### ABSTRACT

Many organizations that produce a portfolio of products for different customers need to ensure that sensitive or restricted content that may appear in some products does not appear in others. Examples of this need include complying with various different countries of sale, protection of intellectual property development, specifically for one customer, and more. For organizations operating under these requirements and producing their products under a product line engineering paradigm that relies on automation in product derivation, there is a need for a method to ensure that the content restrictions have been met in the derived products. This paper describes an auditing method that meets this need. It was created for use in the Second Generation Product Line Engineering approach, that is being applied by Lockheed Martin in their ACES-SHIP cockpit system product line.

#### Categories and Subject Descriptors

D.2 [Design tools and techniques]: product line engineering, software product lines, domain modeling, hierarchical product line

#### General Terms

Management, Design, Economics.

#### Keywords

Product line engineering, software product lines, feature modeling, feature product, bill-of-materials, hierarchical product lines, variation points, product families, product portfolio, product configuration, product derivation, product audit, second generation product line engineering

#### 1. Introduction

A significant challenge for many product line engineering (PLE)

organizations is verifying that capabilities and content restricted for use in a limited class of products is not inadvertently leaked into other products outside of this limited class. Examples of this problem include:

- **Stance compliance:** In PLE organizations that sell products in different countries, legislative differences might require a capability by law in one country and forbid that same capability under the laws of another country. For example, feature enabling rights on nonmilitary are required in Switzerland countries, but not allowed in Japan [1].
- **IP protection:** In PLE organizations that create custom product instances for different companies, a custom or business-oriented capability paid for by one customer might represent generalized intellectual property that must never be used in the products sold to another company.
- **International Traffic in Arms:** In PLE organizations that create military or national security products that are sold in multiple countries, the government of the country where that PLE organization resides may have strict laws on the type of capabilities that can be exported to countries around the globe (for example [2]).
- **Classified information protection:** In PLE organizations that produce military systems that involve classified information, it may be necessary to strictly segregate that information away from non-authorized versions of the system that do not use the classified content.

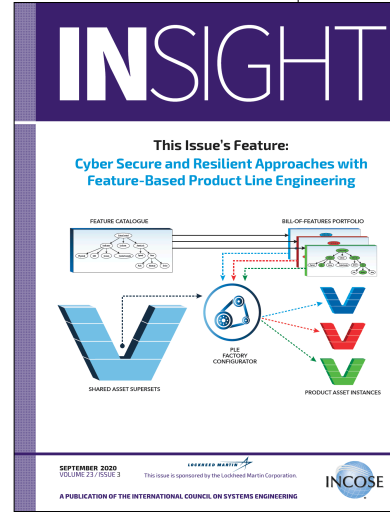
The cost of inadvertently leaking restricted content can be extraordinarily high. Because these restrictions are often based on public safety laws, government use rights, or intellectual property laws, mistakes can result in large fines or legal judgments, restricted court cases, negative media coverage that damage the reputation of a brand, or an extensive case/crisis response time.

In this paper we describe a method for verifiably protecting restricted content in product instances using the Succession Contract Product Line Engineering (SCPLE) approach [3][4]. This work is based on industry experience with the ACES-SHIP cockpit system, managed by Lockheed Martin Mission Systems and Training Division using SCPLE tool and methods, as well as experience with other commercial SCPLE practitioners. The ACES-SHIP Cockpit System is an integrated warfare system developed on over 100 aircraft models in the U.S. Navy and the services of key U.S. allies across the globe. The issue of protecting restricted content is a critical concern in the ACES-SHIP instances built for a diverse customer base.

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<http://dx.doi.org/10.1145/2493272.249329>

## Feature-based PLE in security-intensive settings

- Can PLE work in a case where some of the products' content is classified, or classified at higher levels, than other parts?
- Raytheon and General Dynamics have written about an effective approach to apply PLE in secure environments and in conjunction with System Security Engineering.



### Applying Feature-Based Systems and Software Product Line Engineering in Unclassified and Classified Environments

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processors and defense companies are reaping the benefits of feature-based product line engineering and management (FBPLE) in those situations and seamlessly span unclassified and classified environments (Gregg et al. 2015) (Kraeger et al. 2014) (Lamm et al. 2011). These benefits include talent while granting access to classified material, leveraging employees who are sovereign states, and optimizing system production and maintenance for an enterprise we present the architectural design and accompanying business factors and its analysis that compare unclassified and classified digital assets are used in automated generation of unclassified and classified product line activities occur within a single logical enterprise spanning multiple comprising multiple security zones?

which can be managed as an information system, and includes software, hardware design artifacts, team schedules & other management artifacts, and more content is a collection of one or more information system systems with rules-driven control logic, enabling a granular view which enables or disallows information in processed.

technology or Technical Data controlled under either the U.S. International Traffic in Arms Regulations or the U.S. Export Administration Regulations.



## Feature-based PLE and Agile

- As DoD follows industry trends in Agile development, can Feature-based PLE play effectively in these arenas?
- PLE is not applied in isolation.
- Raytheon, Lockheed Martin, General Dynamics, and (for good measure) General Motors have all shared their experience, which amounts to a resounding “yes.”

26th Annual INCOSE International Symposium (IS2016)  
Edinburgh, July 18-21, 2016

### The Best of Both Worlds: Agile Development Meets Product Line Engineering at Lockheed Martin

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**Abstract.** Agile development has long been touted as way to optimize software development team efficiency and improve project success. Product line engineering (PLE) brings large-scale improvements in cost, time to market, product quality, and more. Can these two paradigms work in concert with each other? This paper details the experience of Lockheed Martin as it introduced large-scale agile development practices on one of its largest and most successful product line engineering efforts.

#### Introduction

Agile software development refers to a group of software development methods in which requirements and solutions evolve through collaboration between self-organizing, cross-functional teams. It promotes adaptive planning, evolutionary development, early delivery, continuous improvement, and encourages rapid and flexible response to change [1]. Its adherents tout higher quality systems, delivered faster, which much better match customer needs and expectations.

Systems and software product line engineering, or “product line engineering (PLE)” for short, is a way to engineer a portfolio of related products in an efficient manner, taking full advantage of the products’ similarities while respecting and managing their differences. Considering a portfolio as a single entity to be managed, as opposed to a multitude of separate closed products to be managed, brings enormous efficiencies in production and maintenance; these efficiencies are delivering order-of-magnitude improvements in engineering cost, time to market, staff productivity, product line scalability, and quality [10].

What happens when an organization tries to apply both of these groundbreaking, organization-changing methodologies at the same time? Can they work together at all? Is PLE, which relies on cross-product planning and well-entrenched coordination, compatible with Agile, the very essence of which is exceedingly short feedback loops and the ability to pivot as needs change?

This paper conveys the experience of Lockheed Martin, the world’s largest defense contractor, as it is applying PLE and Agile together on one of its largest and most important projects. Not only is the project highly visible with demanding requirements, it is also very large, comprising some 10 million lines of code. This setting would challenge either methodology by itself, putting both of them together is yielding many lessons. At the end of



# Feature-based PLE and Digital Engineering / Model-Based Engineering

- As DoD leads industry trends by mandating advanced digital engineering and model-based approaches, Feature-based PLE becomes critical.
  - “Nobody builds just one”
  - Early generation product line engineering approaches are intractable for digital engineering
- Raytheon, Lockheed Martin, General Dynamics, and (for good measure) General Motors have all shared their experiences.

### Product Line Engineering Meets Model Based Engineering in the Defense and Automotive Industries

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**ABSTRACT**  
Product line engineering and model based engineering are two powerful engineering approaches that can bring significant advantages to system engineering projects. This paper explores how these approaches, Feature-based Engineering and Model-based Engineering, are used together to improve and enhance system engineering. The authors describe how they have used these approaches to improve system engineering in the defense and automotive industries.

**CCS CONCEPTS**  
Software and its engineering → Software product lines

**KEYWORDS**  
Product line engineering, model-based engineering, feature modeling, feature profiles, variation points, variation points, product portfolio, product configuration, second generation product line engineering, PLE factory, AEGIS Combat System

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DOI: 10.1145/3506529

**1. INTRODUCTION**  
Model based engineering (MBE) refers to a system engineering approach that employs models as an integral part of a system's engineering process. Models typically bridge the gap between engineering analysis and product realization. The models are used to analyze and predict the behavior of the system, typically, one that is "close" to the final implementation or realization. This information can be used to refine, adjust, or stress test the system before the final implementation or realization. This information can be used to refine, adjust, or stress test the system before the final implementation or realization. This information can be used to refine, adjust, or stress test the system before the final implementation or realization.

**2. FEATURE-BASED ENGINEERING**  
Feature-based engineering (FBE) refers to a system engineering approach that employs features as an integral part of a system's engineering process. Features typically bridge the gap between engineering analysis and product realization. The features are used to analyze and predict the behavior of the system, typically, one that is "close" to the final implementation or realization. This information can be used to refine, adjust, or stress test the system before the final implementation or realization. This information can be used to refine, adjust, or stress test the system before the final implementation or realization.

**What is Product Line Engineering?**  
Product line engineering (PLE) is a way to organize a portfolio of related products in an efficient manner, taking full advantage of the products' similarities while respecting and addressing their differences. Raytheon, one of the world's largest defense contractors, is applying PLE and MBE together and combining the benefits of each. This paper will show how Raytheon is using the two methodologies to support each other and the benefits it is bringing to its users.

### How Missile Engineering is Taking Product Line Engineering to the Extreme at Raytheon

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**Model Based Engineering and Product Line Engineering: Combining Two Powerful Approaches at Raytheon**

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**Product Line Engineering**  
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# Feature-based PLE in a V&V-intensive environment

- Few sectors come close to A&D in terms of the cost required to validate systems.
- Aerospace companies have reported up to 8-fold improvements in the time to generate a certification package, cutting the time from weeks to days.
- Lockheed Martin reports that V&V can in many cases be shared among multiple members of a product line, saving significant time and money.

### Product Line Engineering on the Right Side of the "V"

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**ABSTRACT**  
Product line engineering (PLE) is well known for the savings it brings to organizations. This paper shows how a very large, in-service system and software product line is achieving PLE-based savings in their verification and validation phase of development. The paper addresses how to achieve the sharing across product variants while the products being tested are evolving over time. Additionally, we will give a program's set of system criteria to help reduce the time to generate a certification package. Case studies have, in the past, most often focused on the development activities involved in the creation of system artifacts - activities on the left side of the "V". PLE literature rarely acknowledges and tests the potential savings available from the testing side, but case studies focusing on how to gain those benefits in practice are not plentiful. This paper shows how a very large, in-service system and software product line is achieving PLE-based V&V savings. The product line that is the subject of this paper is the AEGIS Weapons System, a large and complex naval command and control system in wide use in several navies around the world. The developing organization is Lockheed Martin, the world's largest defense contractor, employing 125,000 people worldwide. The paper confirms that significant savings can be achieved from sharing V&V activities and artifacts across product variants in a product line, but the story of how it does so takes a unexpected twist. How do you manage that sharing when the products you are testing are continuously evolving in response to updated requirements and the need for additional variants? We will show how technical management policies drive V&V-based savings. Finally, a long-standing issue in PLE-based testing is whether to test on the domain side or the application (product) side of the product derivation process. We will show how Lockheed Martin addresses that question pragmatically for AEGIS.

**2. AEGIS**  
The product line being described here is the AEGIS Weapons System, which is the most command-and-control component of the AEGIS Combat System. AEGIS is a highly integrated naval ship combat system in service on the U.S. Navy and elsewhere. AEGIS creates and destroys countless numbers of the U.S. surface fleet for the next several decades. The AEGIS Combat System is capable of simultaneous warfare on many fronts: anti-air, anti-surface, anti-submarine, and strike warfare. AEGIS, as a carefully chosen functional subset, is deployed on some 100 naval vessels in the U.S. Navy, seven of which are U.S. Navy ships. The globe, versus the U.S. coast Guard, and even land-based ballistic missile defense installations. AEGIS is a system that protects us from airborne attack from aircraft or missiles. It detects airborne threats, plans how to engage them, and launches missiles to intercept and neutralize them (Figure 1).

The mission of AEGIS includes:

- self-defense (protecting the host platform from attack)
- area air defense (for example, protecting a naval task force that includes the host platform)
- long-range air defense and ballistic missile defense (for example, protecting a geographical area from long-range missile attack)



## Summary

- The release of ISO/IEC 26580 is good news for the systems engineering community in general, and A&D in particular
  - Can be readily and unambiguously mandated in RFPs and contracts
  - Can be readily and unambiguously applied by contractors in their proposals and deliverables
- The better news is that Feature-based PLE does not need a break-in period for A&D to learn the ropes
  - It's been here all along, and continues to be ready to serve