Engineer Your Competitive Advantage

Feature-based Product Line Engineering in Aerospace and Defense

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onePLE

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

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

Independent Development
Systems are engineered independently, without taking advantage of commonality. No reuse or sharing.

Branch-and-Merge
Each new system created by branching from of a similar system. Maintenance attempts reuse by manual N² monitor for opportunities to merge across branches.

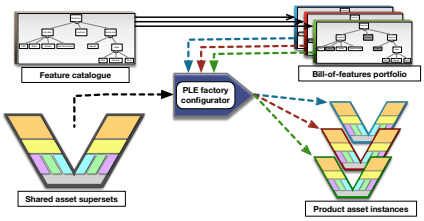
Discipline-centric Var Mgmt
Variation management techniques in a tool or discipline enable sharing and potential automation in one discipline, but results in silos and dissonance across other tools and disciplines.

Clone-and-Own
Each new system created by cloning a copy of a similar system, and then maintaining independently. 100% reuse on day one. 0% reuse and sharing every day thereafter.

Reuse Repository
Collection of assets are put into a repository for reuse by others. Engineers search repository in hopes of finding assets to clone-and-own. Opportunistic and ad hoc reuse, with no sharing.

1st Generation PLE
Collection of "core assets" in a repository for manual clone-and-own reuse within the product line. Strategic reuse, with no automation or sharing.

Early Generation Product Line Approaches



Feature-based Product Line Engineering

Product Line Engineering (PLE) Defined

ISO 26580 Methods and Tools for Feature-based PLE

Product Line:

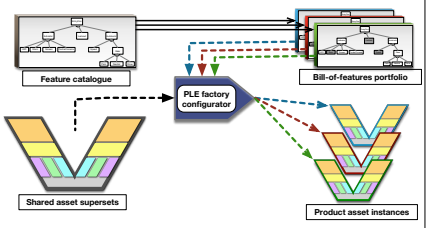
A family of similar products or systems with variations in features.

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

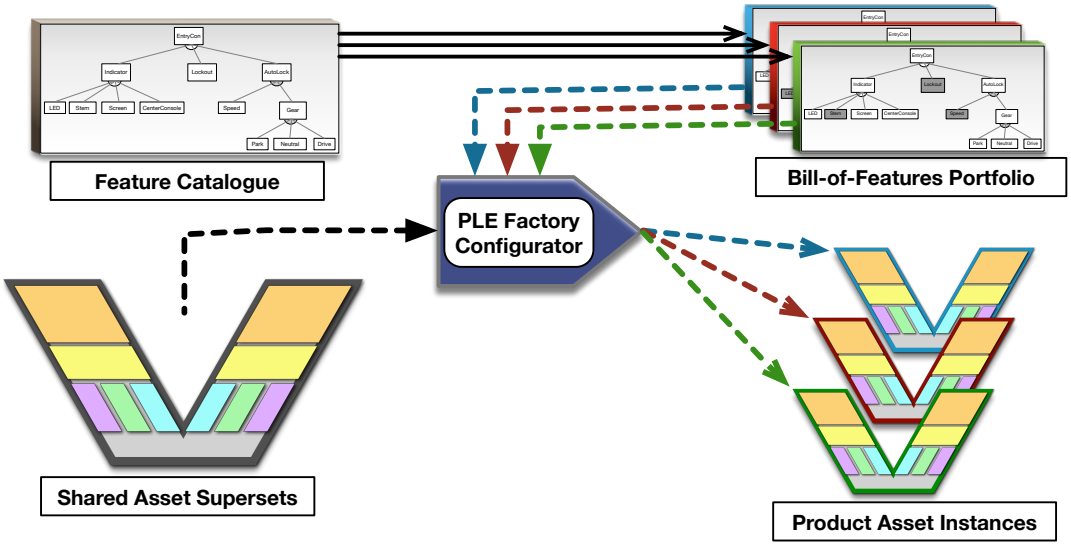


Figure from ISO/IEC 26580
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https://www.iso.org/standard/43139.html

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

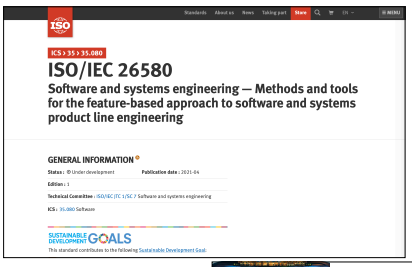
- Although the standard has just been finalized, Feature-based PLE has been in commercial practice in the A&D sector for nearly two decades
  - compiling hundreds of millions of dollars in cost avoidance each and every year
- The approach is being adopted or is already in widespread use by most of the 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

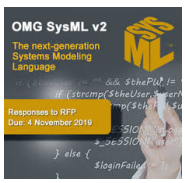
LOCKHEED MARTIN	GENERAL DYNAMICS	gm	Raytheon Technologies	GE Aviation
AEGIS Weapon System for US and International Navies	Live Training Transformation: US Army, Air Force, Marines. Plus enterprise initiative.	One of the largest and most complex product lines, comprising millions of instances per year	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**

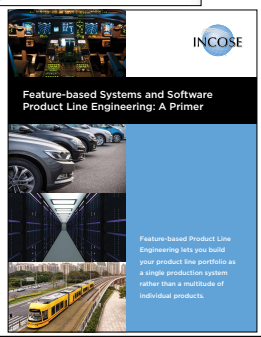
“Change is good. You go first.”

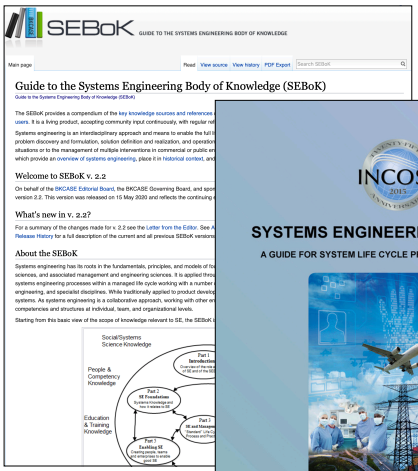
- When it comes to Organizational Change, technology is easy and people are hard
- “Feature-based PLE sounds great, but we’re different — it won’t work here…”
- Engineering organizations are justifiably risk-averse

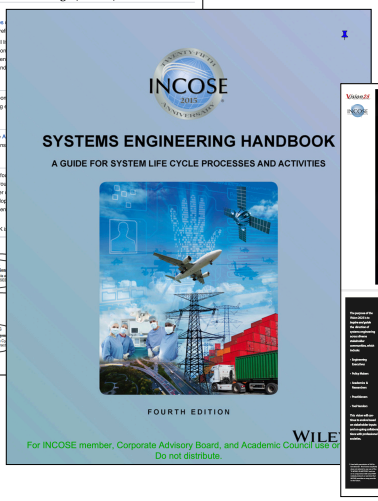
Lowering the risk of organizational change by elevating Product Line Engineering to a standard practice in the industry





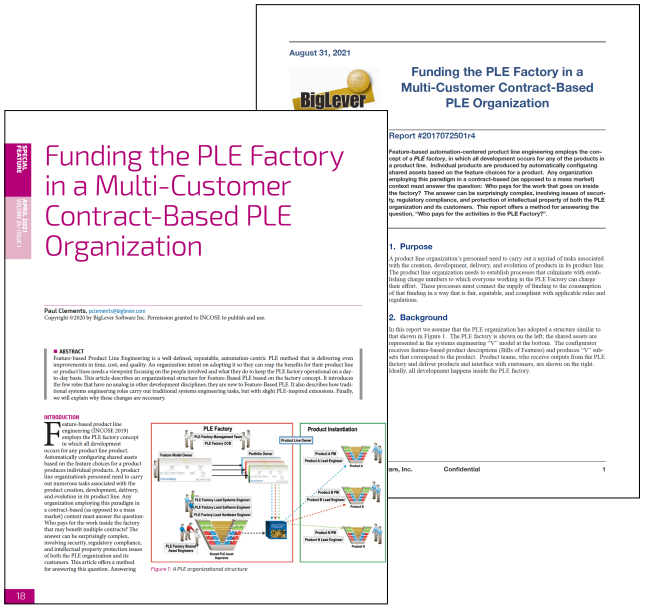






Feature-based PLE in a multi-contract funding context

- 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

BigLever

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

Report #2017072501r4

Feature-based automation-centered product line engineering employs the concept of a *PLE factory*, in which all development occurs for any of the products in a product line. Individual products are produced by automatically configuring shared assets based on the feature choices for a product. Any organization employing this paradigm in a contract-based (as opposed to a mass market) context 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 its customers. This report offers a method for answering the question, "Who pays for the activities in the PLE Factory?".

1. Purpose

A product line organization's personnel need to carry out a myriad of tasks associated with the creation, development, delivery, and evolution of products in its product line. The product line organization needs to establish processes that culminate with establishing change numbers to which everyone working in the PLE Factory can charge their effort. These processes must connect the supply of funding to the consumption of that funding in a way that is fair, equitable, and compliant with applicable rules and regulations.

2. Background

In this report we assume that the PLE organization has adopted a structure similar to that shown in Figure 1. The PLE factory is shown on the left; the shared assets are represented in the systems engineering "V" model at the bottom. The configurator receives feature-based product descriptions (Bills of Features) and produces "V" subsets that correspond to the product. Product teams, who receive outputs from the PLE factory and deliver products and interface with customers, are shown on the right. Ideally, all development happens inside the PLE factory.

Confidential 1

SPECIAL FEATURE

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

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ABSTRACT

Feature-based Product Line Engineering is a well-defined, repeatable, automation-centric PLE method that is delivering even improvements in time, cost, and quality. An organization intent on adopting it so they can reap the benefits for their product line or product lines needs a viewpoint focusing on the people involved and what they do to keep the PLE factory operational on a day-to-day basis. This article describes an organizational structure for Feature-Based PLE based on the factory concept. It introduces the few roles that have no analog in other development disciplines; they are new to Feature-Based PLE. It also describes how traditional systems engineering roles carry out traditional systems engineering tasks, but with slight PLE-inspired extensions. Finally, we will explain why these changes are necessary.

INTRODUCTION

Feature-based product line engineering (INCOSE 2019) employs the PLE factory concept in which all development occurs for any product line product. Automatically configuring shared assets based on the feature choices for a product produces individual products. A product line organization's personnel need to carry out numerous tasks associated with the product creation, development, delivery, and evolution in its product line. Any organization employing this paradigm in a contract-based (as opposed to a mass market) context must answer the question: Who pays for the work inside the factory that may benefit multiple contracts? The answer can be surprisingly complex, involving issues of security, compliance, and intellectual property protection issues of both the PLE organization and its customers. This article offers a method for answering this question. Answering

PLE Factory

Product Instantiation

Figure 1: A PLE organizational structure

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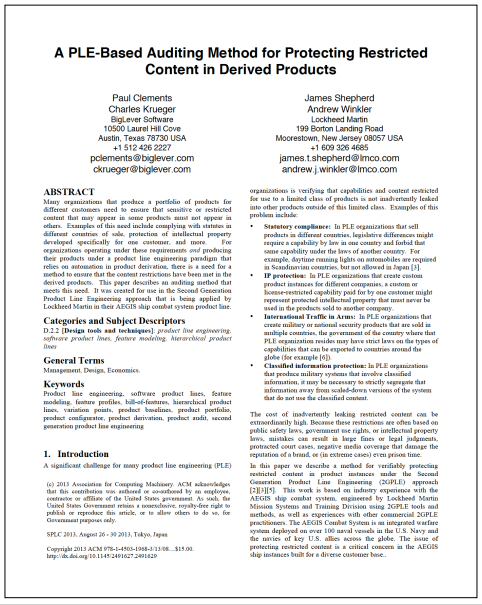
Feature-based PLE and export control compliance

- 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 must not appear in others. Examples of this need include complying with statutes in different countries of sale, protection of intellectual property developed 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 AEGIS ship combat system product line.

Categories and Subject Descriptors

D.2.2 [**Design tools and techniques**]: *product line engineering, software product lines, feature modeling, hierarchical product lines*

General Terms

Management, Design, Economics.

Keywords

Product line engineering, software product lines, feature modeling, feature profiles, bill-of-features, hierarchical product lines, variation points, product baselines, product portfolio, product configurator, 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 to a limited class of products is not inadvertently leaked into other products outside of this limited class. Examples of this problem include:

- **Statutory 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, daytime running lights on automobiles are required in Scandinavian countries, but not allowed in Japan [3].
- **IP protection:** In PLE organizations that create custom product instances for different companies, a custom or license-restricted capability paid for by one customer might represent protected 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 types of capabilities that can be exported to countries around the globe (for example [6]).
- **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 scaled-down 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, protracted court cases, negative media coverage that damage the reputation of a brand, or (in extreme cases) even prison time.

In this paper we describe a method for verifiably protecting restricted content in product instances under the Second Generation Product Line Engineering (2GPLE) approach [2][3][5]. This work is based on industry experience with the AEGIS ship combat system, engineered by Lockheed Martin Mission Systems and Training Division using 2GPLE tools and methods, as well as experiences with other commercial 2GPLE practitioners. The AEGIS Combat System is an integrated warfare system deployed on over 100 naval vessels in the U.S. Navy and the navies of key U.S. allies across the globe. The issue of protecting restricted content is a critical concern in the AEGIS ship instances built for a diverse customer base..

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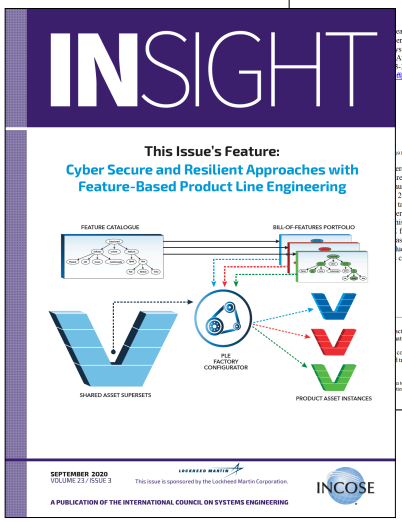
http://dx.doi.org/10.1145/2491627.2491629

Feature-based PLE in security-intensive settings

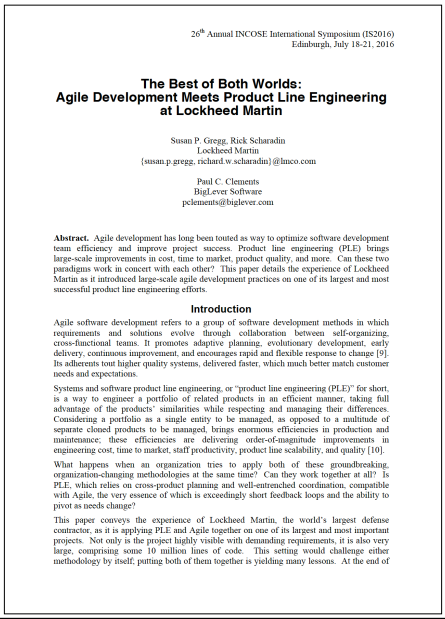
- Can PLE work in a case where some of the products' content is classified, or classified at higher levels, than other parts?
- Raytheon and General Dynamics have written about an effective approach to apply PLE in secure environments and in conjunction with System Security Engineering.




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

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 [9]. 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 cloned 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

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

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

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"

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