

A Strategy for Component Product Lines: Report 1: Scoping, Objectives, and Rationale

Sholom Cohen
Anna Glunt
John Hudak
John McGregor
Gabe Moreno
Fred Schenker

June 2022

SPECIAL REPORT

CMU/SEI-2022-SR-002

Assuring Cyber-Physical Systems

<http://www.sei.cmu.edu>



Copyright 2022 Carnegie Mellon University.

This material is based upon work funded and supported by the Department of Defense under Contract No. FA8702-15-D-0002 with Carnegie Mellon University for the operation of the Software Engineering Institute, a federally funded research and development center.

The view, opinions, and/or findings contained in this material are those of the author(s) and should not be construed as an official Government position, policy, or decision, unless designated by other documentation.

NO WARRANTY. THIS CARNEGIE MELLON UNIVERSITY AND SOFTWARE ENGINEERING INSTITUTE MATERIAL IS FURNISHED ON AN "AS-IS" BASIS. CARNEGIE MELLON UNIVERSITY MAKES NO WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED, AS TO ANY MATTER INCLUDING, BUT NOT LIMITED TO, WARRANTY OF FITNESS FOR PURPOSE OR MERCHANTABILITY, EXCLUSIVITY, OR RESULTS OBTAINED FROM USE OF THE MATERIAL. CARNEGIE MELLON UNIVERSITY DOES NOT MAKE ANY WARRANTY OF ANY KIND WITH RESPECT TO FREEDOM FROM PATENT, TRADEMARK, OR COPYRIGHT INFRINGEMENT.

[DISTRIBUTION STATEMENT A] This material has been approved for public release and unlimited distribution. Please see Copyright notice for non-US Government use and distribution.

Internal use:* Permission to reproduce this material and to prepare derivative works from this material for internal use is granted, provided the copyright and "No Warranty" statements are included with all reproductions and derivative works.

External use:* This material may be reproduced in its entirety, without modification, and freely distributed in written or electronic form without requesting formal permission. Permission is required for any other external and/or commercial use. Requests for permission should be directed to the Software Engineering Institute at permission@sei.cmu.edu.

* These restrictions do not apply to U.S. government entities.

DM22-0577

Table of Contents

Abstract	Error! Bookmark not defined.
1 Introduction	1
1.1 Enterprise Vision and Problem Statement	1
1.2 The Component Line Product and Rules	1
1.3 Documenting the Component Product Line Strategy	3
1.4 Rolling Out the Product Line Strategy	5
2 Product Line Background	7
2.1 Corporate Product Line Approach	7
2.2 Government Component Product Line	9
2.2.1 Component Product Line Roles	10
2.2.2 Relationship Among Component Product Line Roles	13
2.2.3 Summary of Roles and Artifacts	15
3 Defining Objectives of the Component Product Line Strategy	17
3.1 Pillar 1: Develop the marketplace	18
3.2 Pillar 2: Establish Acquisition Freedom of Action	23
3.3 Pillar 3: Create and increase warfighting effectiveness	26
3.4 Pillar 4: Reap economic benefits	29
3.5 Pillar 5: Sustain the Component Product Line Strategy	32
4 Next Steps	36
5 Glossary of Key Concepts	37
6 Acronym List	39
References/Bibliography	40

List of Figures

Figure 1:	Product Line Strategy: From CPLSM to Integration-Ready Components in the Marketplace	14
Figure 2:	Pillars to Achieve the Enterprise Vision via the Product Line Strategy	18

List of Tables

Table 1:	Enterprise Management Strategic Responsibilities	3
Table 2:	Technical Elements of the Product Line Strategy	5
Table 3:	Product Line Definition Applied to a Systems Product Line	8
Table 4:	Component Product Line Roles and Artifact Interactions	15
Table 5:	Action Plan for Pillar 1	22
Table 6:	Action Plan for Pillar 2	25
Table 7:	Action Plan for Pillar 3	28
Table 8:	Action Plan for Pillar 4	32
Table 9:	Action Plan for Pillar 5	34

1 Introduction

1.1 Enterprise Vision and Problem Statement

Today, components are designed and developed for integration into a specific weapon system. To achieve the objectives of the Modular Open Systems Approach, components need to be designed and developed to be integrated into multiple weapon systems.

The enterprise vision of weapon system is: development of these systems will be achieved through the systematic reuse and integration of components.

Achieving this vision can be accelerated by systematically reusing and integrating components built to conform to component specification models. While government organizations have identified systematic reuse as a need in the past, they have encountered problems in meeting this need. These problems include the ability to

- reduce cost and complexity of weapon systems
- avoid proprietary or system-unique development
- shorten lead times for the initial delivery and future upgrades to the weapon system
- define component specification, development, and integration artifacts for reuse in weapon system development and sustainment
- coordinate activities across organizational boundaries with established roles and responsibilities
- build and sustain a vibrant marketplace of components in established product lines, ready for integration in weapons systems
- apply acquisition approaches that support freedom in selecting suppliers and components
- assure the long-term health and success of a reuse approach that improves affordability, time to field, and adaptability to change

This report establishes a Component Product Line Strategy to address these problems. It includes an adoption approach that contributes to achieving the enterprise vision and reusability. This report is supplemented by reports that cover modeling and governance for systematic reuse.

1.2 The Component Product Line and Roles

The definition of component product line¹ is

¹ This and other key terms are identified and defined in Section 5, Glossary of Key Concepts. This component product line definition is based on the definition of software product line as: “a set of software-intensive systems that share a common, managed set of features satisfying the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way.” [SEI 2021]]

a set of components that share a common, managed set of features satisfying the specific needs of a particular market segment or mission. Each component in the product line represents a configuration of those features to a specific feature set as required by a specific weapon system.

A set of roles addresses the strategy for component product lines across the enterprise. These include the following:

1. A **Product line champion** at the enterprise level communicates the vision and strategy and oversees definition and scoping of enterprise product lines.
2. **Component product line managers** serve as operation leads for one or more component product lines to assure successful development of the product lines and use of their constituent components
3. **Component specification modeling teams** capture and represent the scope and capabilities for component product lines in a Component Product Line Specification Model (CPLSM). The team includes a combination of subject matter experts (SMEs), modelers, and consortium participants in the activity.
4. **Component suppliers** use the CPLSM to identify or build components that conform to the specification. These components must be implementation ready.
5. **Weapon system acquirers** have the role of acquiring the system that will be designed and built through integration of components from a component product line to the maximum extent possible.
6. **Weapon system integrators** deliver a weapon system to the acquirer through integration of components from the marketplace along with components that are not in a marketplace product line. These additional components may be unique to the system but could also be from an integrator's in-house component product line.

A more detailed description of each role's activities is in Section 2.2.1 of this report.

The enterprise will provide the following to achieve the vision:

1. **The process and procedures to develop and apply CPLSMs.** These models document the technical requirements for capabilities across all components in a product line. Development of CPLSMs entails significant up-front analysis to arrive at the appropriate component scope. Analysis also contributes to documentation of various component requirements: function, behavior, features, variations, and so on. The analysis may also determine that one component may be integrated with other components, either to extend the component features or as a dependent component. The CPLSMs identify specific combinations of features—feature sets—that are needed by one or more weapon systems.
2. **CPLSMs as government furnished information (GFI) to a supplier community.** These specification models may be used for evaluation of existing products for conformance or as

specifications for further development and implementation. Suppliers may offer an individual component or a full product line of components that conform to the specifications. Components may be pre-existing components or existing components plus a production capability to produce new components for the component product line.

3. **Product line management support.** This support will enable a component product line marketplace. From this marketplace, an evaluation and selection role will identify component specifications for inclusion or integration as part of the weapon system specification. This role selects components from the product line that best address an existing feature set or a feature set configured for a specific weapon system. The role may also collaborate with a product line supplier to instantiate a new integration-ready component for a weapon system.

Table 1 summarize these responsibilities.

Table 1: *Enterprise Management Strategic Responsibilities*

Define and support the process and procedures to develop and apply Component Product Line Specification Models (CPLSMs).
Provide CPLSMs as government furnished information (GFI) to a supplier community.
Create a marketplace for component product lines and the product line management support for use of marketplace components in weapons systems development.

1.3 Documenting the Component Product Line Strategy

The component product line strategy is to derive components from CPLSMs to establish component product lines, build products, or evaluate existing products.

Three reports define the complete Component Product Line Strategy. This first report defines a strategy for achieving multiple component product lines in support of military weapon systems. The report provides an overview of product lines from the acquirer's side—how to specify product line capabilities, provide those CPLSMs to a community of suppliers, and create a marketplace of components. The marketplace is a source for component reuse by weapon system acquirers or integrators, drawing from that source for integration into their delivered products. The paper sets out the concept, identifies the stakeholders in the ecosystem, summarizes what the acquirer side must accomplish to get the benefits of the approach, and proposes a concept of operations (CONOPS) from specification of product lines to integration of systems.

The next two follow-on reports will provide additional Component Product Line Strategy details as follows:

1. A report on modeling concepts to cover the chain of models necessary to support the technical basis of the strategy. This model chain covers component product line development from standards to specifications to architecture, design, implementation, and component testing.

2. A report on the governance principles needed for successful rollout of the technical and business objectives. Governance will support the long-term health of the component product lines and the interactions among roles: product line champion, product line component specification team, developer, supplier, product line manager, user, and evaluator.

The strategy addresses creating a marketplace for integration-ready components whose design and implementation are based on specifications for component product lines. Components from a product line can be configured and instantiated to yield integration-ready weapon system-specific components. A specific component is defined by selection of a configuration of product line features (the feature set), where the feature set establishes a component implementation to provide the capabilities that meet needs of multiple weapon systems.

This Component Product Line Strategy supports the enterprise vision for acquiring mission systems based on integration of components that address common and commodity capabilities. The strategy will influence industry to supply components (new or pre-existing) that conform to the component product line specifications. Suppliers will benefit through increased sales, shorter delivery time, and significant cost savings. Component users who may be other suppliers, acquirers, or integrators will benefit from a marketplace of components to meet weapon system needs. The report examines characteristics of the strategy in terms of the extent to which

1. **Addressing technical and business issues allows government to benefit from component product lines.** Benefits are realized through time-to-field or cost savings and quality and performance improvements. These are the outcome of systematic reuse resulting from applying the component product line strategy.
2. **Specification of product lines at successive layers of granularity can achieve component to component integration.** Components may stand alone, may deliver capability to other components, or may require other component features to extend their scope. This layered strategy achieves the greatest benefit to the government. This approach entails significant up-front analysis to arrive at elements that support Integration of elements at different levels of granularity.
3. **A systematic, strategic approach to component usage can succeed.** Government-provided specifications for product lines of components for reuse allow vendors to become suppliers for an enterprise component product line by
 - a. evaluating their existing products to identify components that are conformant to the specification and determine if those components can satisfy a specification feature set as-is.
 - b. modifying a component or components to meet the specification. These suppliers have existing products and may apply the component specification to determine which required feature sets those products can support.
 - c. developing a component production capability for components that satisfy the specification or rearchitect an existing set of related products into a product line that can address the specification.

- d. developing a product solution that addresses a specific feature set of the CPLSM. This may evolve to broader feature set coverage through an incremental approach to achieve a production capability for components.
- 4. **Government assesses fitness of a supplier’s component for inclusion in the product line.** This determination is based on suppliers’ components meeting the specification, their cost of use, effort to instantiate individual components, ability to address safety/security or performance concerns, and needs for future growth or modification. Fitness determines that the supplier can deliver components that are integration-ready for specified weapon systems in the enterprise.
- 5. **A supplier can develop a model chain to satisfy the CPLSM.** The model chain development applies architecture and design techniques, to provide existing or create new components. The model chain, to be fully described in the second paper in this series, is the series of models to include specification, architecture, design, and implementation. The model chain defines the content needs for each model in the chain and information needs each model user requires.
- 6. **Stakeholders (i.e., weapon system acquirers and integrators) evaluate 1) what is needed by the weapon system program and what is covered in the CPLSM and 2) what is supported from the various suppliers’ components to meet the program requirements.** This allows the government to extend the CPLSM to include additional capabilities or feature sets required by weapon systems. It also allows the government to identify an alternative component, a new development, or a different supplier to provide the additional capabilities or feature sets required by the program.

Table 2 lists the technical elements of the product line strategy.

Table 2: Technical Elements of the Product Line Strategy

<p>Address technical and business issues allowing government to benefit from component product lines.</p> <p>Specify product lines at successive layers of granularity to achieve component to component integration.</p> <p>Define a systematic, strategic approach to component usage.</p> <p>Assess fitness of a supplier’s component for inclusion in the product line.</p> <p>Develop a model chain to satisfy the CPLSM. Model artifacts to include CPLSMs, feature sets, supplier components or models, supplier product line implementations (or links to those implementations), test platforms, and test data</p> <p>Evaluate and select components to address 1) what is needed by weapon systems and what is covered in the CPLSM and 2) what is supported from suppliers’ components to meet the program requirements</p>
--

1.4 Rolling Out the Product Line Strategy

During a component product line scenario brainstorming and analysis workshop (See Appendix A), we identified scenarios that describe the component product line strategy activities. This re-

port identifies five “pillars” based on a prioritized and summarized list of the scenarios. These pillars form the major elements of an action plan for adopting a component product line approach and a roadmap for successful rollout of the strategy. These pillars are as follows:

Pillar 1: Develop the marketplace

Pillar 2: Establish acquisition freedom of action

Pillar 3: Create and increase warfighting effectiveness

Pillar 4: Reap economic benefits (e.g., establish baseline, set targets, track performance, optimize)

Pillar 5: Sustain the Component Product Line Strategy

This Component Product Line Strategy report first presented background to help explain the underlying concepts of a component product line as outlined in Section 2. Section 2 presents the context for component product lines. The context includes the ecosystem of stakeholders and weapons systems that will be developed through integration of components from product lines. Section 3 of this report elaborates each of the five pillars, providing example action plans to be refined by the enterprise to establish the product lines, identify roles and responsibilities, and execute the Component Product Line Strategy. Section 4 summarizes next steps in elaborating the strategy. Sections 5 and 6 provide a glossary of terms and an acronym list.

2 Product Line Background

A conventional definition of a software product line is

a set of software-intensive systems that share a common, managed set of features satisfying the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way. [SEI Framework for Software Product Lines]

Key factors in this definition are that the product line is a set of systems developed in a prescribed way through product line assets.

2.1 Corporate Product Line Approach

The software product line definition has been applied for decades in the corporate model for product lines. A noted example is the engine controller product line developed by Cummins, Inc., a diesel engine manufacturer. That engine controller product line evolved from recognizing the need to develop multiple similar controllers for a variety of different engine categories. At the time, Cummins had numerous product lines under each business unit, but each engine controller development was planned through unique specification and implementation. To meet the realities of cost, schedule, human resources, and customer needs, these multiple, unique developments were consolidated under a common architecture and development approach that would meet the system requirements of an entire product line. The results and subsequent improvements over three decades have been a broad-based engine controller product line that has produced individual controller products with much lower effort, a broader set of features, and higher quality in terms of engine efficiency and satisfaction of regulations.

Table 3 applies the product line definition to the system product line for Cummins engine controllers.

Table 3: *Product Line Definition Applied to a Systems Product Line*

Product Line Definition	Definition Applied to the Cummins Engine Controller Business Units
A set of software-intensive systems	The engine control systems for each Cummins business unit (e.g., automotive, power, marine, auxiliary equipment)
Share a common managed set of features	Fuel control, temperature management, power control. Variations for engine application, fuel category, size, and weight, etc.
Designed to meet the specific needs of a particular market segment or mission	Commercial, production vehicle; specialized off-road vehicle; and non-vehicle markets
Developed from a common set of core assets	Product line architecture, architecture-conforming components, product line test systems
Developed in a prescribed way	Cummins development and integration tools; prescribed development methods

This approach succeeded because Cummins had total authority over the development of the products, the staffing of the development organization, the development methods, and the contact with the customer.

While approaches for commercial product lines and those for weapon systems have several common characteristics, the government approaches generally fail to succeed for the above reason of complex inter-organizational relations.

- The “Lego” model: Some may oversimplify the product line approach. The notion of building a collection of common “Lego pieces,” primarily software, for specific functions that can be fit together into larger computing elements, has been promoted for almost 40 years. If properly abstracted, a design may be composed in this fashion, but the common understanding of how to use these pieces across the list of organizations stated above makes such agreement through to implementation impractical. In addition, the low granularity of these pieces creates a complex integration of configuration and variation management elements.
- Repositories: Usable solutions are contributed without any plan for how they should be re-used or how the solutions may be used together, if such integration is even possible. The repositories lack upfront agreement as to usability and reusability of solutions beyond conformance to some standard, along with preplanning to support integration of the individual solutions to support weapon system development.
- Best of breed approach: This approach searches across a related set of systems for those that seem to have the best subsystem or component to satisfy a collection of needs. Again, the individual element may be excellent, but the collection of “bests,” if not built to work together, cannot be integrated after the fact.

- Total system product approach: This approach cannot be relied on when the next system differed from the system product to any extent. Where the components are too small in granularity, the total system approach of systematic reuse pegs the granularity at too large a level. Even allowing for variation in the system for subsequent tailoring places architecture and design decisions into the hands of the original developer. While some decisions may be consistent with those needed to satisfy subsequent use, most decisions are not consistent or in agreement with those needed for future development. In addition, the total system approach usually locks the original developer into subsequent weapon system development to realize reuse.

A NASA study provides a comprehensive sampling of these approaches [NASA 2005].

2.2 Government Component Product Line

This section defines the context for product lines of components considering overall weapon system development that will integrate these components. The context includes an ecosystem for weapon system development defined by the scope of systems under acquisition and development, the stakeholder community for those systems, and the respective roles of the stakeholders. The component product line consists of

- a set of components
- the set components in the product line that share common and variant features or capabilities
- connections between each component product line and a particular capability
- a set of core assets that are used in developing components in the product line
- a prescribed approach applied in development and use of the components in the product line

This section examines that ecosystem from the perspectives of

- systems supported within the enterprise
- capabilities that recur across these systems
- selection of capabilities ready for implementation via components in a product line
- specified meta-model for CPLSMs and modeling guidelines for the suppliers of components in a product line
- capabilities modeled to CPLSMs for use by suppliers (Suppliers may apply the specification to identify existing conformant components or for development production capability for components.)
- weapon system modeling and development through integration of existing components or integration of components instantiated from a supplier's production capabilities

Weapon system development is quite different from the commercial development activity of Cummins, Inc. described in Section 2.1. This significant difference requires an alternative approach to the use of product lines to achieve systematic reuse of system elements across weapon

systems. Operating within Department of Defense acquisition regulations, acquisition and development is split across program management areas, developers, integrators, suppliers, airworthiness authorities and end-users. In addition, the legal requirements, data rights, and contracting limitations may critically affect the ability of the enterprise to establish and maintain a component product line approach for developing and sustaining weapon systems. The strategy proposed by this paper highlights a separation of activities and concerns across stakeholders for the enterprise to achieve success in applying a component product line approach. A government–industry ecosystem collaborates in elaborating the Component Product Line Strategy for establishing component product lines and applying them in integration of weapon systems. Government has traditionally been the specifier, and in the Component Product Line strategy a government-led specification team will be creating specifications for components. The acquirer will be the government manager for weapon system acquisition.

2.2.1 Component Product Line Roles

Government and industry stakeholders are responsible for creating the component product lines, evaluating existing components in a product line for integration, instantiating new components that will be part of the acquired weapons systems, and assuring the component product lines are properly vetted, used, and sustained for specifying, implementing, and acquiring weapon systems.

The Component Product Line Strategy identifies numerous roles that participate in achieving the Enterprise Vision via the Strategy.

Product Line Champion – The Product Line Champion is an enterprise role that must promote and communicate the vision and component product line strategy by

- assigning responsibility for operations to a **Product Line Manager** role and for specification of components to **Component Specification Modeling Teams**
- collaborating with product line managers to identify and qualify **Component Suppliers** for development of components
- maintaining the component product line strategy by enforcing component use by **Integrators** and **Acquirers**
- developing enterprise-wide support for component evaluation and selection by acquirers and integrators

Component Product Line Manager – The manager serves as operational lead for one or more component product lines. Component Product Line Managers

- coordinate with the **Product Line Champion, Component Suppliers** and across the enterprise to maintain and sustain the component product line strategy
- survey weapon system requirements to identify and scope capabilities to be captured as component product lines. These capabilities, provided to the component system modeling team,

may include software and/or hardware, and systems/subsystems/components as candidate component product lines.

- develop and maintain the CPLSMs for each product line and assess components coming from suppliers for conformance to CPLSMs with **Component Specification Modeling Teams**
- organize product line artifacts for distribution and maintain a source of information about the artifacts for other component product line roles
- collaborate with Army Aviation programs to support evaluation and selection of component product lines for the weapon system and assure that the components are the basis of weapon system acquisition and integration. This collaboration examines specifications, the appropriate variation and feature sets for specific components, and components from the marketplace.
- maintain the roster of component product lines, available components, and current users of components from the product line and all relevant artifacts. Collect metrics on use of models and implementations including error reports, delivery and maintenance records, and trade study results to determine need to extend, upgrade, or retire product line lines.
- provide feedback from component product line users to the CPL modeling team and suppliers
- perform supply chain management activities to identify potential suppliers that can develop components, address timing of new deliveries and releases, project needs, future growth, technology trends, identifying and applying the data rights necessary for receiving conformant components from suppliers to be used by integrators

Component Specification Modeling Teams – The specification modeling team concentrates on modeling capability and functional requirements in a CPLSM. This team

- captures the scope and capabilities in models that represent use cases, use restrictions, operational behavior, as well as functionality, user and test documentation, lifecycle, and logistics constraints
- delivers CPLSMs and all supporting data to the **Product Line Manager** in the form of technical data packages
- performs model analysis to assure model consistency, determine model size, document capability and model testing traceability, and to assess safety and security hazards
- provides guidance in use of models
 - for suppliers: how to use CPLSMs in development of components or component production capability
 - for integrators: how to model and implement their weapon systems (e.g., interfaces) to integrate component models
- manages variation across the components that affects feature set selection in areas of functionality, resource utilization, deployment variations, error handling, and cybersecurity

- utilizes industry standards, weapon system specifications, existing component documentation, and component systems as sources for engineering analysis to specify CPLSM content. Content may be requirements for all components, variations selected for a specific feature set, and terms of use for component product line artifacts, including the structure for reporting on results of use.

Component Suppliers – A component supplier accepts CPLSMs and related feature sets as GFI. This role maintains the current supplier relationship to weapon system integration as tier 1 (integrator) to tier 2 or tier 3 suppliers. These suppliers perform the following to produce fully implemented components that conform to the CPLSM and feature set, ready for integration:

1. Perform component development through to deployment and validation to the CPLSM by
 - a. mining existing components, modifying and augment them to produce product line conformant components
 - b. developing or applying an existing component product line production capability for component instantiation
 - c. performing component analysis to assure conformance to the specification, to determine component size, to document specification traceability, to provide estimates of timing and other resource utilization, and to analyze for hazards in safety or security
2. Test a representative sample of possible instantiations of components from the product line.
3. Deliver a technical data package (models, implementation, test systems, test results) for each component evaluation or selection by the acquirer or integrator.

Weapon System Acquirer – Acquirers use CPLSMs as a basis for developing capability requirements for the weapons system performance specification. The CPLSM and associated feature set may also be used to identify and select component implementations for the acquisition. Acquirers perform one or more of the following tasks:

1. Collaborate with the **Product Line Manager** to identify available components and component suppliers
2. Evaluate fitness of components within the product line to address the weapon system performance specification, optimize the use of CPLSMs in defining requirements, and use appropriate components for realizing those requirements.
3. Select an integration-ready component for a weapons system under acquisition
4. Select a qualified **Component Supplier** to address specific weapon system requirements

Weapon System Integrator – A weapon system integrator produces the implemented weapon system by integrating components from the product line along with other system-unique elements. The integrator must evaluate components to select them for development of a weapon system. The integrator must be aware that full integration readiness may require extending the component, for

example, by adding an adapter between the component and the weapon system or building capability outside the component for a missing or incomplete feature requirement. The weapon system integrator relies on the marketplace content to perform the following:

1. Determine that the component addresses the complete feature set required for the weapon system, if capabilities must be added, or if adaptations must be applied.
2. Assure component instances will be ready for integration, meeting system requirements.
3. Review and apply documentation to assure that the appropriate system environment to integrate a component from the product line exists.
4. Perform integration of the weapon system component models including model analysis to virtually integrate and perform system-wide analysis across all component models.
5. Test components in unit and integration testing settings to satisfy their integration readiness.
6. Provide the solution implementation for the weapon system that can integrate instantiated components to satisfy the system specification.
7. Complete all system integration, testing, and other activities leading to certification and delivering the weapon system that address the system specification of a product acquisition organization.

2.2.2 Relationship Among Component Product Line Roles

The Component Product Line Strategy is realized through established relationships across the ecosystem of stakeholders, component product lines, weapon systems, and supporting infrastructure for enterprise weapon system development. The strategy separates responsibilities across the spectrum of stakeholders, focusing on the traditional roles of each.

Error! Reference source not found. summarizes of the relationships among the roles and the list that follows elaborates.

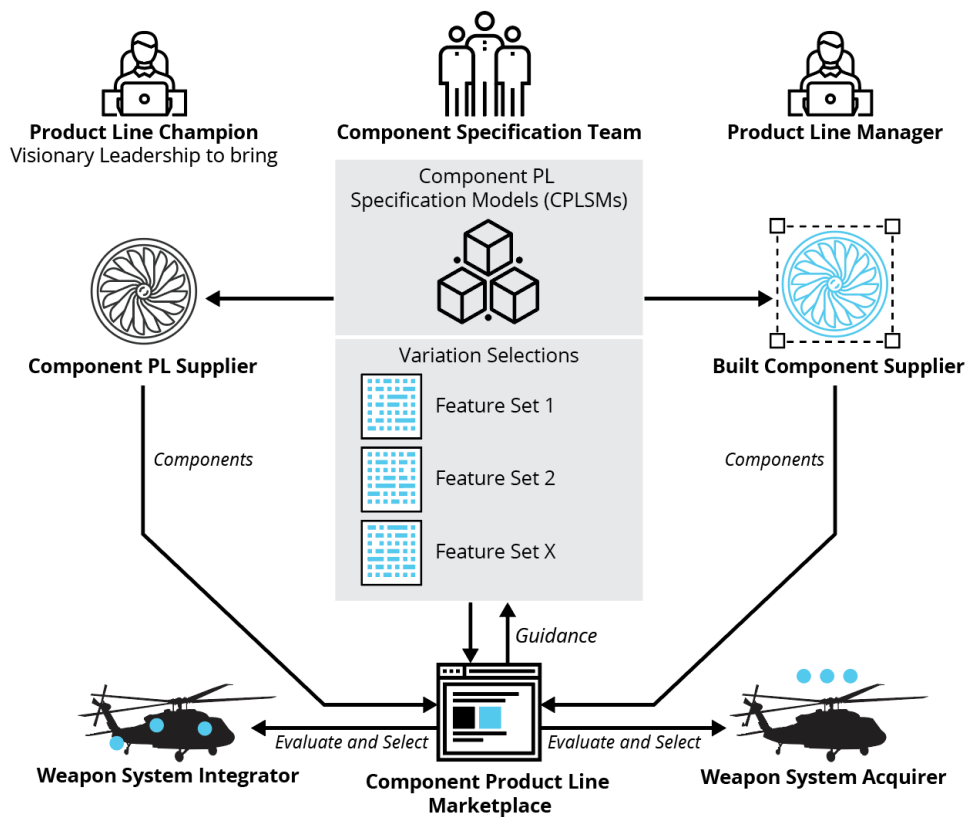


Figure 1: Product Line Strategy: From CPLSM to Integration-Ready Components in the Marketplace

- The *Product Line Champion* is the advocate and change agent to realize the product line strategy. The champion fosters a culture where the product line approach is recognized as the core acquisition, development, and integration approach for systematic reuse of components across enterprise weapon systems. Together with the Product Line Manager, the champion is responsible for the strategy and assuring the strategy is carried out into practice.
- The *Product Line Manager* works with acquirers and integrators to support their evaluation and selection of components, and also assures that product line components are properly maintained, and product lines operations are managed effectively.
- The *CPLSM Modeling Team* delivers specification models and feature sets.
- *Component Suppliers* provide the components of the product line. The *Built Component Supplier* (right side) may have legacy components that address a complete or nearly complete feature set. These components populate the product line. The *Component PL Supplier* (left side) will construct a production capability from which the Component PL Supplier may instantiate a new component to a pre-defined or new feature set. Other component suppliers may create a limited production capability for selected feature sets. These production capabilities may mature into a full capability for any feature set.

- The *Weapon System Acquirer* evaluates and selects models as a basis for specification and components or components to be instantiated from a component PL supplier for a specific weapon system acquisition.
- The *Weapon System Integrator* performs a similar evaluation and selection of components ready for integration in a weapons system for delivery to the acquirer.

These relationships lead to a Component Product Line Concept of Operations (CONOPS) for the enterprise. An activity diagram models the high-level interactions for this CONOPS across the ecosystem. This CONOPS covers the development and exchange of models and implementations that define component product lines and their instantiation for integration into weapon systems. The CONOPS answers questions such as

1. Who participates?
2. What does each participant contribute?
3. What does each participant provide to the ecosystem?
4. What do they receive?
5. What gaps exist in the proposed strategy?

The second report in the series, the Modeling report, will elaborate on the structure and models that constitute the artifacts. The CONOPS also provides a decision and risk framework for exploration in the Governance report, the third in the series of PL Strategy reports.

2.2.3 Summary of Roles and Artifacts

Error! Reference source not found. provides product line roles and relationship to three sets of component product line artifacts:

1. The component product line specification models
2. The component marketplace contents
3. The integration-ready component

Table 4: Component Product Line Roles and Artifact Interactions

Role	Component Product Line Specification Models	Component Product Line Marketplace	Integration Ready Components
Product Line Champion	Determines scope of component product lines and processes for advancing Product Line Strategy.	Establishes the strategic relationships with existing and potential component suppliers to establish a marketplace for providing product lines of components to users.	Directs Product Line Managers across the various product lines to assure enterprise components are used in weapon system development.
Product Line Manager	Directs modeling of product line component specifications. Provides these models	Coordinates activities bringing supplier-developed components into the component	Works with weapon system acquirer and integrator to en-

Role	Component Product Line Specification Models	Component Product Line Marketplace	Integration Ready Components
	to potential suppliers for enrichment of the component marketplace.	marketplace. Assures components from suppliers conform to specifications in order to enter the marketplace.	sure product line components are integrated into their systems.
Component Specification Modeling Team	Applies enterprise processes to model product line component specifications and feature sets. Produces the CPLSM to support component architecture definition and design to include variation points.	Produces evaluation criteria to apply in determining component conformance for entering the marketplace.	Works with acquirers and integrators to support their evaluation of CPLSMs for selection of a specific component.
Component Supplier	Uses the CPLSM to identify existing components that conform, to modify components into conformance, or to develop a product line production capability for conformant components.	Delivers and sustains components in the marketplace. Works with product line manager to evaluate components for conformance.	Coordinates use of the suppliers' own components with acquirers and integrators.
Weapon System Acquirer	Provides feedback to the product line manager or component specific modeling team regarding adequacy of existing CPLSMs given new or emerging needs.	Evaluates and selects components from the marketplace as a basis for weapon system performance specification and as needed for integration.	Directs use of components from a recommended list as GFE in an acquisition.
Weapon System Integrator	Provides feedback to the product line manager or component specific modeling team regarding adequacy of existing CPLSMs given integration issues.	Evaluates and selects components from marketplace to determine extent of component coverage for requirements and of need for modification or tailoring.	Tailors the component for integration into the weapon system.

3 Defining Objectives of the Component Product Line Strategy

Achieving the overall enterprise vision for development of weapon systems requires more than a component product line strategy description. Other initiatives and strategies within the enterprise will also contribute to that achievement. The report so far has laid out a strategy that defines an ecosystem, the players, artifact, and operations. In 2.2.1, the report defined a set of tasks for each of the players or roles and identified information requirements of artifacts for the strategy, those artifacts that must be developed (e.g., models, analysis results, and product line artifacts) or those that must be used.

For the component product line strategy depicted in **Error! Reference source not found.** to succeed, the enterprise must do more than provide the stakeholders with appropriate tasks and products. An action plan must be associated with the strategy for it to succeed and contribute successfully to the enterprise vision. The plan summarized in this paper is built around five “pillars.” (These are the defining objectives terminology used by Table Group Silos, Politics and Turf Wars [The Table Group 2022]) Building support through the pillars will lead to implementation of the Component Product Line Strategy.

The pillars of the Strategy are depicted in Figure 2 and were previously stated in the introductory paragraphs in Section 1:

Pillar 1 - Develop the marketplace

Pillar 2 - Establish acquisition freedom of action

Pillar 3 - Create and increase warfighting effectiveness

Pillar 4 - Reap economic benefits (establish baseline, set targets, track performance, optimize)

Pillar 5 - Sustain the Component Product Line Strategy

This section of the report will elaborate each pillar and provide an example action plan that lists first steps achieving the Component Product Line Strategy.

An important contribution of these Pillars is the identification of business drivers and specific product constraints. Drivers are in general those that are derived from Modular Open Systems Approach (MOSA) goals and objectives. Product constraints include architecture frameworks and architecture requirements as spelled out in the Comprehensive Architecture Strategy (CAS) paper. The Component Product Line Strategy will apply these constraints in specifying CPLSMs and providing guidance to suppliers to best address the business drivers.

Each of these pillars emerges from one of the scenarios developed during a scenario brainstorming workshop that was intended to coalesce enterprise activities around the component product line concept. (See Appendix A.) A scenario specifies the range of lifecycle activities that are performed across the ecosystem to achieve some objective. For each pillar, the plan identifies

1. a range of activities, some of which are identified in this report
2. the stakeholders assigned to perform that activity
3. resources allocated to the activity
4. measures to satisfy performance of the activity has been accomplished

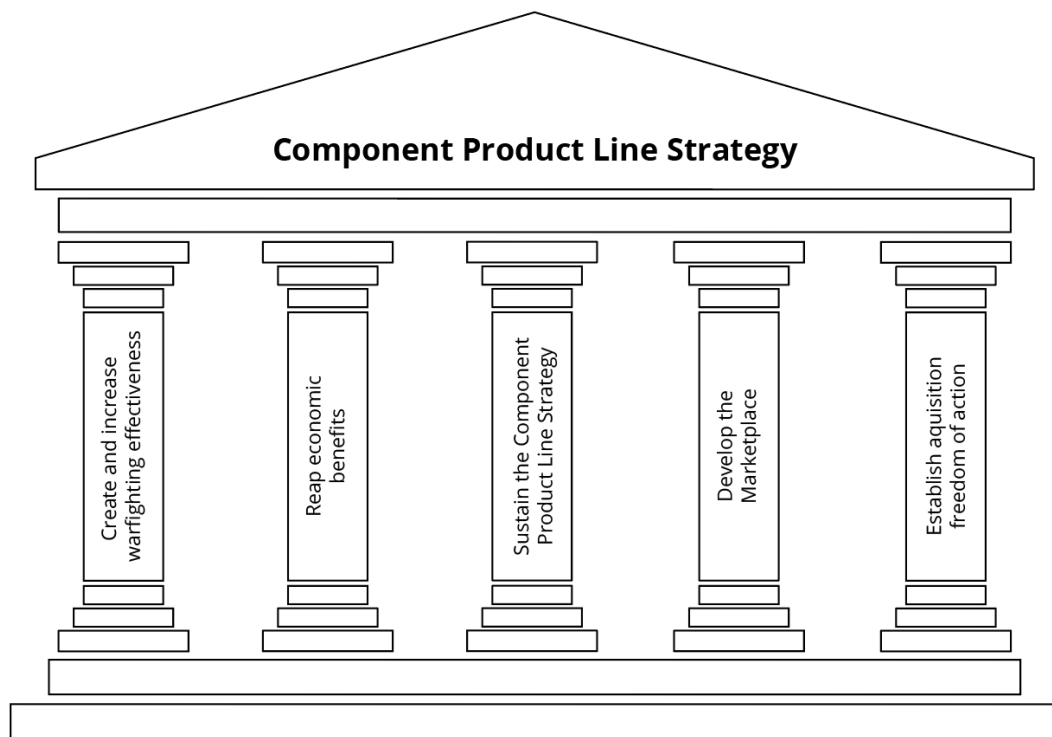


Figure 2: Pillars to Achieve the Enterprise Vision via the Product Line Strategy

3.1 Pillar 1: Develop the marketplace

The first pillar in implementing the strategy is to develop the marketplace that suppliers contribute to in the form of components for a product line. This activity determines modeling and implementation approaches that best address effectiveness of components derived from the product lines. The components must address feature sets required by enterprise weapon systems and must be ready for integration. From models of the components and other user documentation, weapon system integrators must also know the system environment needed to utilize these integration-ready

components. The weapon system acquirer may work with integrators via a statement of work requirement for the integrator to use the marketplace as government furnished information and government furnished equipment for execution of their design and build efforts. In this way, the integrator is directed to exploit the marketplace for the desired exclusive use of product line components for their weapon systems. The ability to provide this direction crosses all the relationship lines among all the stakeholders—the product line champion, product line manager, component specification modeling team, component suppliers, weapon system integrators, and acquirers.

The components in this marketplace are designed to be reusable and constitute product line assets. These assets for reuse are sustained and achieve greater enterprise value than single-use or custom-built components that are centrally controlled. The government recognizes the ability of suppliers to deliver on the specific needs of integrators. The suppliers must provide the components that are integration-ready without incurring additional development costs. The components may already be ready for integration or, in the case of a production capability, require a minimal tailoring or configuration effort to derive integration ready components. Integrators may also be required to build system-specific components and other system elements that are tailored to address unique capabilities within the weapon system. The components from the product lines are integrated with system-specific components by the system integrator to deliver the weapon system to the acquisition authority.

Primary activities or use cases that must be met through this pillar of the strategy include

1. a marketplace exists for reusable components and is sustainable to achieve more for your dollar
2. a marketplace exists for new/novel components
3. government recognizes the ability of product lines to deliver on need

Enacting this pillar will address specific business drivers, including those of the MOSA. The explanation and rationale for these is as follows:

Faster to Field: The product lines constitute major system components for the fleet of aircraft in the family of systems and potentially for the enterprise. The product lines capture capabilities that are common to these systems including variations, allowing for tailoring to specific system needs. The pillar addresses the goal through production of component implementation and the ability to integrate those components into the weapon system with significant schedule savings, reduced risk, and continuous upgrades.

Affordable Life Cycle Costs: When multiple systems share component development and sustainment, the costs to use and integrate those components decreases. Costs are lower for the same reason that that off-the-shelf hardware costs are lower than those for custom-built hardware. The individual system integrators must still understand the need for customization, costs to customize from the product line, and costs to integrate. These are still lower by at least 50 percent from the cost of developing and integrating the same capability as unique, system-specific components.

This pillar also achieves technical or architecture requirements. The supplier developing the component product line must architect for families of systems and for the component product line itself. For the family of systems that is the target set of weapon systems that will integrate components from the component product lines, the component supplier must address the architecture requirements and design of the family to permit integrations of the components instantiated from the component product line. The component product lines must address their specific architecture requirements. The product line architecture must address the needs for commonality and variation, including functional and performance variations. The design must be tailorable to produce components instantiated from the product line to address target weapon system needs and requirements with affordable costs and time to field.

Component product line modeling must address the technical requirements that support tailoring (to include management of variation points) for each specific system in the family. In this way, modeling of a component product line includes description of how to exercise tailoring that can be performed to create a product line instance component for a specific weapon system. Business drivers affect modeling decisions (e.g., how to meet specific quality attributes modeled as variations, or what weapon system-specific options or alternatives to include in the product line) and can address the government, supplier, and integrator side interactions (business interoperability).

The model representations for the component capability include

- functional architecture of functions, operations, and behaviors.
- representation of variation points (functional and software) and feature sets for those points.
- data architecture across the product line to define how data is structured, represented, stored, and transmitted to create models for sharing, secure, and assuring safety.
- hardware architecture with variations that address components in the product line.
- a model of the implementation environment for how the product would be delivered (actual or modeled or both) (when applicable).

Models are layered

- with different levels of detail (government, consortium, supplier/component specific).
- in accordance with commonly used and documented views of software and system architectures.
- by applying definitions such as those from the CAS [Padilla 2018].
- by product lines of lower granularity including infrastructure and utility components.

The CAS suggests at least four categories of architecture, each of which is common to software intensive systems, and may be documented in terms of one or more viewpoints:

1. Functional architecture: The functional architecture documents the functions or capabilities in a domain covering what they do, the data they require or produce, and the behavior of the data needed to perform the function.

2. Hardware architecture: A hardware architecture specification describes the interconnection, interaction, and relationship of computing hardware components to support specific business or technical objectives.
3. Software architecture: a software architecture describes the relationship of software components and the way they interact to achieve specific business or technical objectives.
4. Data architecture: A data architecture provides the language and tools necessary to create, edit and verify data models. A data model captures the semantic content of the information exchanged and semantics of exposed interfaces.

A cross-cutting concern is to establish semantics of the interface behavior beyond data at the interface. The semantics of behavior describes the exchange mechanism/protocol, where control of data takes place, and in what forms data is presented/exchanged at the interface. Each viewpoint is consistent with quality attribute definitions and business drivers of the organization. (These link back to reference architecture requirements.)

Component product line development based on the CPLSM will apply the following approaches:

- Using the product line architecture to include optionality for sets of capabilities, function, data, and information, namely, feature sets.
- Applying environmental constraints and/or applicable reference frameworks (e.g., Future Airborne Capability Environment [FACE] Reference Architecture) that may be part of the architecture requirements included with CPLSMs. These architecture requirements are essential for development and deployment. They are provided by the government to constrain the supplier in implementation of the product line.
- Layering from infrastructure into higher level components offers an asset-based approach that enhances systematic reuse where suppliers integrate across asset layers to create their component product lines.
- Using component-level solutions that comport to the CPLSM feature set requirements and address the minimum needed capabilities, creating the marketplace for integrators to select the product line or component instance that will best address integrator needs. This can occur in at least four ways. The integrator may
 - select an already existing product in a virtual product line that addresses a complete or almost complete feature set for the weapon system
 - direct the supplier to deliver a component instance configured from the component product line to satisfy a specified feature set
 - select a product line package that allows the integrator to establish its own configured component instance needed by the target system.
 - create a component that satisfies the component specification model for one feature set. This approach may evolve to a product line in a use case where the integrator applies architecture and design to accommodate future variation, though only a single feature set is implemented.

Suppliers follow these development approach alternatives to achieve the business goals of affordability in producing system-specific components through the product line. They also select among the alternatives to achieve a clear path for addressing the technical requirements of the CPLSM. The specification constraints inform the supplier and the integrator in making their architecture, design, and implementation decisions. Quality attributes communicated and evaluated by way of selection of component products leads to a marketplace that responds to product line requirements that best address integrator needs and the government requirements.

The application of a component product line strategy also supports testability through repeated use of the same starting point for each component—the CPLSM. Benefits related to testability also include the reduced need, cost, and time for regression testing and airworthiness of the whole mission and/or aircraft system. Previous instances have undergone supplier testing and have a pedigree of integrator use, testing, and qualification. On the quantitative side, both the supplier and integrator can track product metrics such as frequency of use, cost of use, repair history, and user acceptance of products built using the component product line. Metrics can also include a “dashboard” of performance specifications including runtime size, timing, bandwidth requirements, and other subjective measures. The product line manager has the responsibility of verifying and maintaining these records.

Risks to meeting goals and addressing technical requirements include

1. Attribute Concerns – if modeling of capabilities is strictly functional without consideration of broader architecture requirements, the product line may not be sufficiently tailorable to specific system needs and will not be adopted.
2. Modeling Decisions and Reasoning – the government and supplier must have a sufficient understanding of the scope of use of the components instantiated from the product line. If the models and implementation are too narrow in scope, they will not provide sufficient benefits from use, requiring significant effort on the part of the integrator to use instantiated components. If the product line scope is too broad, the product line may be too costly to develop or may not be able to address target system specifics. Given the breadth of coverage, variation will require too much customization or unique development to account for this breadth.

Error! Reference source not found. provides the example action plan for Pillar 1. In the case of this and the other pillars, an enterprise working group must develop that actual plan to implement the Component Product Line Strategy.

Table 5: Action Plan for Pillar 1

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Identify modeling team and product line manager.	Product line manager	Immediately	2 weeks	2 FT	Primary “in-house” stakeholders are on board and functioning.

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Develop strategy descriptions.	Product line manager	Immediately	2 weeks	2 FT	Descriptions are available for distribution across a variety of media.
Create potential marketplace list.	Product line manager	Immediately	2 weeks	2 FT	Supplier list with POCs is created.
Contact potential suppliers.	Product line manager	After list created	2 weeks	2 FT	Suppliers participate in virtual industry day.

3.2 Pillar 2: Establish Acquisition Freedom of Action

The second pillar in implementing the strategy is to establish freedom of action for the acquisition authority. The component product line strategy gives the acquisition authorities greater freedom of action in acquisition. It should support the ability to acquire systems and system components from a broader set of integrators or suppliers. It should also support the ability of the acquirer to recompete existing developments from competitive sources to increase affordability, performance, quality, and decrease time-to-field.

Primary activities or use cases (source scenarios)

1. effectively use the adaptive acquisition framework
2. acquisition freedom of action to re-compete the LSI or supplier
3. current and comprehensive documentation system so “outsider” can join

Business drivers with explanation or rationale

This pillar primarily addresses the business goal of affordability. By opening the integrator and supplier roles to greater competition, contractors are incentivized to deliver solutions that provide lower acquisition costs.

This innovation can also address the business driver of time to field. A competing integrator may offer improvements in fielding new capabilities based on those that are open to competition. A supplier may offer a wider set of features, which can be adapted and tailored for upgrades rather than relying on custom developments for the individual system.

Technical or architecture requirements addressed

This pillar addresses the primary technical driver for an architecture that supports a family of systems. A published CPLSM will link to the family of system architecture that will integrate components instantiated from the product line.

The component product line strategy addresses the technical requirements that support specification of component product lines or acquisition of components from the product line supplier. The

implementation approaches must also support subsequent tailoring of a component from the product line for each specific system in the family. Freedom of action for acquisition within this pillar is supported by enhanced competition from within the supplier community for component product lines. Integrator original equipment manufacturers (OEMs) can develop and integrate solutions based on components from a product line relying on expertise of suppliers. New OEM integrators may enter the competition for large-scale systems responding to their ability to supply outside expertise and greater standardization. The business and modeling decisions address the product line manager, supplier, and integrator roles.

1. Product Line Champion and Managers – incentivize suppliers to build product line component models, the product line production capability, and product line components that capture functionality, behavior, and variation to meet needs of systems across the enterprise. Enforce the freedom of acquirer action by constantly surveying that community for new trends in terms of threats, technology, interoperations, and tactical skills to assure product lines are maintained to address current and future needs. The Manager also works with the training and education community to assure their developments are included in component product line planning.
2. Component Suppliers – work with the government on delivering solutions that provide flexibility in acquisition from OEMs. Suppliers understand the scope, technology evolution, and appropriate acquisition approaches to apply in building component solutions that conform to the CPLSMs. They will realize that they are competing with other suppliers to best address government needs across the enterprise and over anticipated changes and upgrades.
3. Integrators – as users of the Component Product Line, integrators may direct instantiation of components from a production capability or rely on the supplier’s already built components. Acquisition freedom allows the government product line manager to support both supplier roles. The weapon system acquirer may select a specific component or may defer this choice to the integrator. Factors in this decision will be the ability of a component to address a specific feature set. Also, a specific supplier may offer product line solutions, component characteristics, data rights, and schedule that are most advantageous. The acquisition must build time into an integrator’s schedule for component understanding, to assure the component will meet system requirements.

Pillar 2 takes advantage of the product line strategy and its ability to define and update product line capability as often and as necessary to meet changing weapon system needs. Components of a system are not static, and neither are the components that should be available to the market to support the scope of the family of systems. CPLSMs will be continuously updated to reflect changes in technology, threat, mission, and system properties. The specification provides for ease in determining the availability of a product line, discoverability of new opportunities, and usability by integrators. These advantages require an environment in which capabilities are specified and modeled for ease of use and understandability by both the supplier and integrator.

The government or the developers that model component specifications for the product line must assure their models contain sufficient detail to generate (manually or automatically) the documentation of specific components based on a system context. The models must include the ability to perform feature selection for function, behavior, resource constraints, safety, security, and deployment considerations. The initial component specification may not address all these needs but the ease of updating and releasing new versions of a specification supports rapid evolution and improvement. This quality is a benefit of the product line strategy that a component library not based on a single component specification can never meet. It also puts a burden of competition on potential suppliers to be able to rapidly respond to the evolving nature of the component product line specification.

Risks to meeting goals and addressing technical requirements

1. The government risks the ability to identify a sufficient number of suppliers unless it takes an incremental approach to releasing component product line specifications.
2. Components from a product line may fail to address target weapon system need unless suppliers can provide input to shape the product line specification based on attention to existing solutions, even those not yet on the market.
3. Where the product line is based on an industry or government standard, the Product Line Manager should encourage innovation to improve competition and resulting weapon systems. Suppliers and integrators should be allowed to comment on specific tailoring, properties, or other characteristics of the components to be instantiated from the product line to support the acquirer in both short- and long-term acquisition improvements.

Error! Reference source not found. provides the example action plan for Pillar 2.

Table 6: Action Plan for Pillar2

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Identify acquisition organizations that will be product line consumers.	Product line manager	Immediately	2 weeks	2 FT	Primary external stakeholders agree with and endorse the strategy.
Develop roadmap for product line application.	Product line manager, product line champion	After list created	1 month	2 FT	Initial “master schedule” of enterprise product deliveries is available.
Create potential marketplace list.	Product line manager, product line champion	After master schedule	2 months	2 FT	Component product lines are matched to potential users
“Matchmake” suppliers with acquirers.	Product line manager	After marketplace list	1 month	2 FT	Suppliers and acquirers participate in a virtual industry day to share needs and offerings.

3.3 Pillar 3: Create and increase warfighting effectiveness

This pillar addresses the needs of programs to continuously deliver new mission capability to the field through faster upgrades and regular delivery. Currently that time is too long due to accreditation and acquisition delays. Delivery of upgrades is also unpredictable due to unanticipated capability changes. The product line strategy can create or increase warfighting effectiveness by addressing these needs. The strategy should support fielding of systems that are capable of incremental update. Systems fielded through integration of components can see rapid upgrade as revisions to those components occur—changes to a component from a product line will be tested to assure conformance that prevents any side-effects from integration of that changed component. For components that have explicit safety and security requirements, the product line approach should provide rapid upgrade to address new threats, tested to assure no side effects with respect to safety and security. Integrators will be able to take advantage of their current continuous integration and continuous delivery methods by selecting components or directing suppliers to provide components that satisfy these methods.

A related consideration is to deliver operational systems software that is the same software as that used in training systems. The product line strategy should deliver a component product line with variants that can be integrated simultaneously in the operational and training environments. The strategy should result in users of trainers and operational systems seeing the same interactions with upgrades that are in sync.

Primary activities or use cases (source scenarios)

- Create or increase warfighting effectiveness
- Incremental delivery of capability
- Same software in training systems consistent with operational systems

Business drivers with explanation or rationale

1. The main business driver for Pillar 3 is to maintain capability overmatch. In the current environment, a need for system improvement and upgrade must go through the entire acquisition cycle. The CPLSM identifies in advance the potential needs for these upgrades and can support the customer need to sustain overmatch. Where the requirements have been allocated to components, the need to maintain overmatch of capability can be addressed via updates to CPLSM. Suppliers can sustain their product lines in accordance with the specification updates and continue to support integrator needs to deliver the overmatch capabilities.
2. A goal of suppliers is to address the need for rapid upgrade and increasing warfighter effectiveness as one benefit of increased maintainability. This benefit is associated specifically with Pillar 2, to enhance freedom of action in acquisition, and Pillar 5 to sustain the product line and weapon systems that integrate components from the product line. A “standard component” from a library cannot achieve the benefits of effectiveness without the full acquisition lifecycle applied to the GFI component.

Technical or architecture requirements addressed

1. Pillar 3 addresses the primary technical driver for an architecture that supports a family of systems. A published capability model will provide a range of alternatives and possibly anticipate the needs of future upgrades. A prebuilt component cannot address all needs, but the specification of a product line will inform the supplier of the desired extensibility to meet the need for upgrade. The potential suppliers must determine, in consultation with the government, the schedule for these upgrades constructing the product line architecture with necessary extensions, options, or alternatives to handle those changes in the future.
2. Suppliers do not need to provide solutions for those upgrades but should be capable of modeling and implementing those upgrades when they move to the current need status. However, this approach enables suppliers to innovate and anticipate new capabilities for the product line resulting in outpacing the threat.
3. A specific approach to achieving overmatch is to require component capabilities that can be achieved through a product line that addresses both operational and training needs. A delivered system that cannot be operated in an optimal manner, for example in use of the latest upgrades, may result from inadequate or unavailable training. Keeping the training and operation in sync is another architecture requirement that this scenario must address.

Achieving Pillar 3: The component product line strategy must address the technical requirements for current overmatch needs. But as threats, technology, and computing resources evolve, achieving overmatch will rapidly evolve. This evolution may, in some cases, be anticipated, but in other warfighting environments the specific overmatch needs cannot be adequately anticipated. The business and modeling decisions address the government, supplier, and integrator sides.

1. Government – Require suppliers to build product line capability models that capture functionality, behavior, and variation to meet current system needs across the family. Also define architecture requirements for extensibility and maintainability to address change with minimum side effects that can rapidly improve warfighting capability.
2. Supplier – Work with the government on understanding current warfighting needs and the anticipated improvement to maintain overmatch across some forward-looking timeframe. Suppliers often possess the best understanding of the scope, technology evolution, and appropriate acquisition approaches to apply in building solutions to the product line capability models for achieving overmatch and optimal warfighting capability. They will realize that they are competing with other suppliers to best address government needs to improve warfighting capability. They will deliver on overmatch requirements through anticipated changes and upgrades or changes that are not anticipated but can be addressed through extensible solution architectures for the product line.
3. Integrators – As users of the CPLs, integrators may perform instantiation of components from the product or rely on the supplier to perform that role. In either case, this scenario can address a situation where the OEM need not be the focus of acquisition for enhanced warf-

ighting capability or maintaining overmatch. This role may be achieved through the component product line. The scenario frees the OEM to address other areas of maintenance in optimizing overall system performance or safety, for example.

A CPLSM continually evolves and can be extended. Its initial creation should be defined by this evolutionary need and specific extensions, even when not specifically anticipated, can be address in the product line architecture and implementation. The integrator can then easily enhance the warfighting capability of the system through integration of new components from the product line rather than building them for the specific system. The entire Family of Systems (FoS) benefits from the overmatch capabilities brought through the product line.

In parallel to upgrading systems through integration, operational systems provide operational feedback into the component product line capability model and into resulting supplier product lines. The FoS provides a wealth of operational data that documents component needs—whether for defect repair, optimization, or to close capability gaps. These needs are addressed via changes or enhancements to the capability models and then the models are delivered to the suppliers as part of a continuous improvement cycle. Integrators benefit from the sharing of need across the FoS even when the specific system of a specific integrator did not encounter the need for change.

The range of potential features, options, alternatives, and upgrades can be addressed by capturing that potential in a scenario list for initial modeling. Models may not provide all the specific capabilities in an initial release but can anticipate changes and then “turn them on” in later releases. Similarly, the supplier product line solutions will not implement all potential features or variations, but knowing the scenario plan, suppliers can construct a product line architecture capability for addressing downstream change and upgrade. The direct input to market of such government needs is of great benefit to the warfighting effectiveness. It will shorten the cycle-time for delivery and fielding of upgrades, improve the delivery of those capabilities via competition, and reduce the integration time, costs, and potential defects. The result of addressing this pillar is enhance overmatch by delivering components based on a consistent PL architecture.

Risks

A major risk to the success of this pillar is to overburden the scenario list with too many options, alternatives, and variations. While modeling for the scope of this pillar is not a significant risk, without some well-planned prioritization, the component product line may fail to reach an initial viable coverage of feature sets. The risk of need for too much flexibility or too much functionality can result in delays to delivery, costs to sustain too broad a scope, and sacrifices of quality for quantity of capabilities. The ecosystem of government, suppliers, and integrators should be involved in the scenario list prioritization and establishing timelines to address continuous integration of new capabilities along with the achievement of the overmatch goal.

Error! Reference source not found. provides the example action plan for Pillar 3.

Table 7: Action Plan for Pillar 3

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Identify acquisition organizations that will be product line consumers	Product line manager	Immediately	2 weeks	2 FT	Primary external stakeholders agree with and endorse the strategy.
Develop roadmap for product line application	Product line manager, product line champion	After list created	1 month	2 FT	Initial “master schedule” of enterprise product deliveries is available
Create potential marketplace list	Product line manager, product line champion	After master schedule	2 months	2 FT	Component product lines are matched to potential users.
“Matchmake” suppliers with acquirers	Product line manager	After marketplace list	1 month	2 FT	Suppliers and acquirers participate in virtual industry day to share needs and offerings.

3.4 Pillar 4: Reap economic benefits

Given a potential marketplace, this pillar allows the stakeholders to determine what product lines will yield the greatest benefit and how to determine the return. For a product line to be sustainable it must be affordable. Affordability is directly related to cost and value. Cost will include cost to develop the component product line, both the CPLMS on the government side and the component product line asset base on the supplier side. These costs should be one criterion in evaluating feasibility of applying a product line approach for the components in the proposed product line. Value to the government is determined by achieving improvements in affordability for weapon systems and other goals supported by a proposed product line specification, product line architecture, or the resulting components of the product line. Using the product line strategy makes each weapon system more affordable through systematic reuse of components across a family of weapon systems.

Primary activities or use cases

1. Apply cost model for hardware, infrastructure, software [SEI 2005]
2. Reap benefits from economies of scale

Business drivers with explanation or rationale

The primary business driver for this pillar is the need to address improvements to system affordability. Component product lines deliver those capabilities captured in the CPLSM. The component from within a product line is integrated as part of the acquired weapon system. Current acquisition

may reuse components from previous developments in a new weapon system, but those components require extensive and often unanticipated tailoring for the new weapon system. Under the product line strategy, a CPLSM addresses not only the common requirements, but anticipated changes that will be required for use in new weapon systems. The variations (options or alternatives) for those new systems and guidance to suppliers for delivering a product line architecture and other assets are essential in creating the weapon system specific component for integration. The product line achieves affordability by sharing those up-front engineering costs across all potential users of the component product line.

Technical or architecture requirements addressed

This pillar addresses the primary technical driver for an architecture that supports a family of systems by determining costs in the following categories:

1. Costs to government to create the CPLSM
2. Costs to supplier. These may be estimated costs to
 - a. create the component product line capability (product line architecture including hardware, software, data models, implementation, etc.) that must be recouped through use of instantiated components
 - b. costs of a supplier to bring existing components into conformance with the CPLSM and one or more feature sets
3. Costs to integrators to use the component including selection of the component (cost to understand and evaluate for choice among competing product lines), licensing component use, tailoring the component or contracting with suppliers to tailor the component, and costs of changes to the weapon system as already designed or built to support component integration.

The cost model should also provide estimates for building a component outside the product line or factors to consider as a basis of estimating the costs to tailor a legacy component not built for use with this specific weapon system.

The resulting analysis must also consider the potential economies of scale – the reduced costs of use of a component based on the number of weapon systems planning to use components from the product line.

The activities associated with this pillar include

1. Steps to gather information and structure the argument – costs of component specification, cost of instantiating components from a product line, cost of using already built components, costs of managing the product line, improvements to affordability offered by the CPLSM.
2. Costs for development, reuse, and sustainment not easily determined or estimated and estimates of the number of planned or delivered systems with need for components of the product line

3. Results of implementing the strategy – determine the percentage improvement in development and sustainment costs from multiple use of components from multiple product lines across the enterprise. This can predict costs for use of product lines across a life cycle that may extend over 20 years.

We consider the following stakeholders in this scenario:

1. Product Line Manager (This may be a single stakeholder organization or the specifying organization and separate organizations that manage product lines.)
 - a. costs to create the CPLSM are known, if specification is complete, or may be estimated
 - b. costs to maintain configurations of components that address feature sets, using the appropriate variants
 - c. obtaining and promoting use of utility and infrastructure components for mission level components and determining impact on specifier or supplier costs
 - d. costs of the Product Line Manager organization as needed to support the product line
 - e. in an exercise, several different feature set selections can be applied to evaluate and select components from the product line. Costs to use each component can be computed to determine the optimal strategy for managing the product line
 - f. the total cost is computed, given input from all stakeholders
2. Component Suppliers
 - a. costs of the suppliers to develop the production capability or to bring already built components into conformance. These may be estimated or captured from potential suppliers or prior development activities. The configuration of each asset (module, component, system) is priced.
 - b. costs of the unique pieces of the product are provided to the PL manager for use in the formula.
 - c. supplier organizational costs are provided to the PL manager for use in the formula.
3. Weapon System Integrator
 - a. costs to evaluate the marketplace offerings and make tradeoff decisions to select components
 - b. depending on source of component:
 - c. supplier costs to tailor a component for integration via the production capability
 - d. cost of acquiring an integration ready component from the supplier
 - e. costs to the integrator to integrate a selected component into a weapon system
 - f. costs to modify and perform integration of the component for a weapon system that is already designed or built. These costs may be adaptations to use the component or more substantial changes required to modify parts of a weapon system that are affected by the component (e.g., dealing with side effects to safety/security)

4. Weapon System Acquirer
 - a. costs to work with Product Line Manager to evaluate and select CPLSMs for a system performance specification
 - b. costs to tailor the CPLSM for the specific system
 - c. if a specific component is to be required, costs to evaluate and select from the available components in the product line or those that can be produced from a supplier’s production capability

Risks to meeting goals and addressing technical requirements

A primary risk to achieving affordability is in anticipating potential weapon systems that will be using the product line as a source for the specific component. If the desired component is from a product line with limited use, the integrator or acquirer may be required to pay the entire development and sustainment costs. Otherwise, the supplier will bear all costs. A lack of credible competition in the product line if there are few users may also affect affordability—a sole supplier will see little value in sustaining a product line for a small set of users.

Error! Reference source not found. provides the example action plan for Pillar 4: Reap economic benefits.

Table 8: Action Plan for Pillar 4

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Gather historical costs.	Product line manager, product line champion	Immediately	4 weeks	2 FT	Provide a cost breakdown by program or type of development
Develop a list of cost drivers (e.g., size, complexity, and variations).	Product line manager	Gather costs	1 month	2 FT	Provide the cost driver list for review and make adjustments.
Develop basis for cost estimates.	Product line manager	After identifying drivers	2 weeks	2 FT	Create a cost estimator tool that accepts drivers and values for calculation.
Run validation test.	Product line manager, product line champion, suppliers	After tool-based estimates	2 months	2 FT	Compare actuals with estimates from tool.

3.5 Pillar 5: Sustain the Component Product Line Strategy

Finally, how are the product lines used and sustained over time, both in terms of evolving capabilities and evolving technology? The “Achilles’ heel” of software product lines has for decades

been the long-term sustainment of the product line assets, evolution of the product line, and support to users of product line products. This concern exists for industrial and government product line developments and for systematic software reuse in general. Planning for the product line must include sustainment through the lifetime of the product line, not just to the creation and initial use of the product line products.

These concerns are applicable to the Component Product Line Strategy. This pillar addresses issues in the strategy with respect to

1. maintaining the CPLSM (Product Line Managers, Component Specification Modeling Team)
2. maintaining the components and production capability (Component Suppliers)
3. supporting the marketplace of component product lines (Product Line Manager or Product Line Champion)
4. assuring adherence to the strategy by all stakeholders

This pillar also includes a sustainment process that determines which updates should be made to a supplier's production capability or to a supplier's components, how to support acquirers or integrators using product line components, and when to retire a product line.

Primary activities or use cases

1. Increase reliability and maintainability
2. Sustain product moves to provider's side

Business drivers with explanation or rationale

The primary business drivers for this pillar are both affordability of weapon systems and preserving overmatch of capability. The long-term health of the product line includes continuous review of use of components from the product line. This review determines which capabilities in a CPLSM require continued support, which require changes and updates, which should be retired (never used), and which new capabilities should be added to the specification. Sustainment of the CSPLMs drives efforts by the suppliers to assure their components remain competitive in the marketplace. This strategy supports viability of the product line for weapon system acquirer and integrator use. Continued viability is accomplished through the supplier role in maintaining currency of the product line.

The need for overmatch can also be supported by monitoring and addressing the CPLSM. As threats, new technology, and changing system interactions (e.g., need for enhanced interoperability) emerge, the product line must respond. The costs of these upgrades can be shared across users' components without affecting affordability.

Technical or architecture requirements addressed

The evolution of hardware including network, processors, and bus technology are factors suppliers must constantly assess. The CPLSM may not change, but this evolution can be centrally studied with results provided to existing or emerging suppliers. The result is anticipating technology direction and assuring that the product line will support that evolution.

The need for this pillar is predicated on the sharing of maintenance across users of product line components to lower error reports, increase affordability, and maintain capability overmatch. The current state requires each final weapon system product to be maintained on a singular basis. Proper implementation of this pillar results in suppliers improving reliability and maintainability by planning for multiple uses of the core asset for a variety of delivered products. The product line manager should set a goal for decrease in defect reports by as much as 50 percent and ease of upgrade by a similar reduction in cost.

A further aspect of the pillar is to eliminate vendor lock on “common software.” The longer a CPLSM and components that conform to the specification remain viable, the greater likelihood that new suppliers will enter the marketplace. In the current environment, the government acquires products and must sustain them or contract with a sustainment vendor or organization. Under the Component Product Line strategy, sustainment of CPLSMs can be performed by a consortium or other organization as provider of specifications and suppliers sustain components to continue participation in the product line.

The role of product line manager also factors into this pillar. While the government specifies the capabilities for components, the specification and modeling organizations may not be suited to maintain the integrity of the product line over time in terms of continuous testing and certification. The specification organization may choose not to work directly with the marketplace or provide an intermediary role in working between the Component Product Line specification team, component suppliers, and weapon system acquirers and integrators. Once the product line is in place, these roles can be handed off to a product line manager role for long term sustainment of the product line. The manager assesses use of the product line assets, use of products, technology directions, changing threats, and marketplace drivers to determine how best to address both the supplier and user needs.

Risks to meeting goals and addressing technical requirements

A clear risk is sustaining the product line beyond its “expiration date.” At some point, the existing specification or product line assets will no longer address user needs and must undergo major overall. At that point, the product line may be ready for retirement and replacement with a new product line.

Error! Reference source not found. provides the example action plan for Pillar 5.

Table 9: Action Plan for Pillar 5

Activity	Stakeholder	Start	Complete	Resources	Success Criteria
Gather historical costs.	Product line manager, product line champion	Immediately	4 weeks	2 FT	Provide a cost breakdown by program or type of development.
Develop a list of cost drivers (e.g., size, complexity, variations).	Product line manager	Gather costs	1 month	2 FT	Provide the cost driver list for review and make adjustments.
Develop basis for cost estimates.	Product line manager	After identifying drivers	2 weeks	2 FT	Create a cost estimator tool that accepts drivers and values for calculation.
Run validation test.	Product line manager, product line champion, suppliers	After tool-based estimates	2 months	2 FT	Compare actuals with estimates from tool.

4 Next Steps

The Component Product Line Strategy Report is Report 1 in a series of three reports. Two future reports will elaborate on the strategy:

Report 2 – Model Report

1. Explores the model chain across the various roles: specifying, designing and implementing components for a product line.
2. Describes model content needed to support use of models to carry out the various roles and to evaluate and select appropriate components for acquisition or integration.
3. Documents an example that illustrates an application of the model chain concept.

Report 3 – Governance Report

1. Evaluates the experience of other agencies that have already moved in the direction of the component product line strategy.
2. Examines how the strategy affects the government and its roles in managing artifacts and establishing weapon system performance specification in using a product line approach to satisfy those needs.

An Action Planning Workshop is necessary for bringing the component product line strategy into effect. The workshop can be built around

- using draft activity lists from this report to seed discussion in workshop
- conducting workshops and making assignments to address action items under each pillar
- beginning execution of the Component Product Line Strategy

5 Glossary of Key Concepts

General Product Line Concepts

Concept of operations (CONOPS) for a product line. The CONOPS defines the participants, activities, work products, dependencies, and management for operating a product line.

Feature – a user-visible aspect or characteristic of a system. Features may be required, optional, or alternative across components in a product line.

Feature model – a collection of features used in product-line engineering to specify and communicate common and differing aspects of the products in a product line. The model organizes features to guide structure, reuse, and variation across all phases of the CPL life cycle.

Software product line – “a set of software-intensive systems that share a common, managed set of features satisfying the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way. [SEI Framework for Software Product Lines]

Variation – the way in which two or more product variants differ from each other. A variation may be optional, alternative, or other differing features of a product that lead to individual products in a product line

Product Line Strategy Roles

Component Product Line Manager – operations lead for one or more component product lines to assure successful development of the product lines and use of their constituent components

Component specification modeling team – captures and represents the scope and capabilities for component product lines in a Component Product Line Specification Model (CPLSM)

Component supplier – uses the CPLSM to identify or build components that conform to the specification. These components must be implementation ready

Product Line Champion – at the enterprise level, communicates the vision and strategy and oversees definition and scoping of enterprise product lines

Weapon System Acquirer – specifies and acquires the weapon system that will be built through integration of components from a component product line to the extent possible

Weapon System Integrator – delivers a weapon system to the acquirer through integration of components from a component product line with weapon system-unique elements

Product Line Strategy Artifacts

Component product line – a set of components that share a common, managed set of features satisfying the specific needs of a particular market segment or mission. Each component in the product line represents a configuration of those features to a specific feature set as required by a specific weapon system or other product.

Component product line model chain – the succession of models and modeling concepts necessary to support the technical basis of the component product line strategy. This model chain covers component product line development from standards to specifications to architecture, design, implementation, integration, and test.

Component Product Line Specification Model (CPLSM) – model that captures and represents the scope and capabilities for component product lines. Includes function, behavior, features, variations, etc. The models also support component understanding, selection and tailored use by weapons system acquirers and integrators.

Component Product Line Marketplace – the source of all component artifacts and related information reused by weapon system acquirers or integrators. Component specification modeling teams and component suppliers provide their artifacts to the marketplace. Acquirers and integrators evaluate and select components from the marketplace for their weapon systems.

Component production capability – a supplier approach that derives new products based on feature sets or feature selection. The capability includes the core assets that include development tools, methods, test frameworks, processes, and an environment to instantiate new integration ready components from the core asset base on demand or to rapidly tailor existing components.

Feature Set – a combination of features that are required for a component to address requirements for a specific weapon system acquisition or development.

6 Acronym List

CAS	Comprehensive Architecture Strategy
CONOPS	Concept of Operations
CPLSM	Component Product Line Specification Model
FoS	Family of Systems
MOSA	Modular Open Systems Approach
OEM	original equipment manufacturer
PL	product line

References/Bibliography

URLs are valid as of the publication date of this document.

[Atkinson 2005]

Atkinson, David. Software Strategy for Reuse Study, Final Report. *National Aeronautics and Space Administration, Exploration Systems Mission Directorate*. Report number AC1L1-52. 2005. <http://dx.doi.org/10.13140/2.1.3399.3604>

[Padilla 2018]

Padilla, Marcell. Comprehensive Architecture Strategy (CAS). U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) Aviation Development Directorate (ADD). July 12, 2018. <https://www.dsp.dla.mil/Portals/26/Documents/Publications/Conferences/2018/DSP%20Workshop%20July2018/DSPWorkshop-Day4-180712/DSPWorkshop-5Padilla-180712.pdf?ver=2018-08-01-150712-570>

[SEI 2005]

Clements, Paul; McGregor, John; Cohen, Sholom. *The Structured Intuitive Model for Product Line Economics (SIMPLE)*. Software Engineering Institute, Carnegie Mellon University. February 2005. <https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=7611>

[SEI 2021]

Product Line Strategy Scenario Analysis. White Paper (Appendix A to this report)

[The Table Group 2022]

[Silos_Model_2.pdf \(de7pikzj4hvyk.cloudfront.net\)](#) (Retrieved 1 June 2022)

Appendix: Product Line Strategy Scenario Analysis Workshop Report

EXECUTIVE SUMMARY

The Army's Integrated Mission Equipment (IME) project with the Software Engineering Institute (SEI) held a scenario analysis workshop consisting of two half-day sessions. The workshop produced scenarios for an enterprise-level product line strategy (PLS) that could be applied to Army aviation acquisitions. The content of this report is reflected in the strategy, but concepts evolved during creation of the Strategy Report

The workshop followed an agenda similar to the one used in Phase 1 of the Architecture Tradeoff Analysis Method (ATAM) evaluation to capture business drivers, technical constraints, and scenarios. The IME/SEI workshop participants created 18 scenarios. A consolidation activity refined 10 of the scenarios to 5 for scenario analysis. The following scenarios were chosen for analysis:

- Scenario 1: Create a Marketplace for New/Novel Components
- Scenario 2: Establish Acquisition Freedom of Action to Re-Compete
- Scenario 3: Create or Increase Warfighting Effectiveness
- Scenario 4: Reap the Benefits from Economies of Scale
- Scenario 5: Sustain the Product Line and Weapon Systems that Integrate Components

Scenarios 1-3 were analyzed in depth during the workshop, and Scenarios 4-5 were proposed for future analysis. Scenario 4 was chosen based on prior SEI work in product line benefits and has since been jointly analyzed outside the workshop; those results are included in this paper. Scenario 5 consolidates concepts for sustaining components and weapon systems that integrate those components. The elaboration of this scenario was created for this report and requires follow up to integrate IME concepts for sustainment. We plan to conduct follow-on activity to jointly examine model views as listed in Scenario 1.

1 Introduction

This paper presents the evaluation of a PLS for U.S. Army components that follow a product line acquisition approach. The evaluation took place at the Technology Development Directorate (TDD) of DEVCOM at Ft. Eustis on August 30-31, 2021. The evaluation was performed by members of the IME project and the SEI and followed modified steps of an SEI ATAM. While the ATAM evaluation examines a software system's architectural decisions considering the system's desired quality, this method is suitable for evaluating the PLS by examining product line development decisions in light of desired business drivers.

The evaluation adapted only the first phase steps of the ATAM evaluation. That phase usually includes presentations, but for the product line evaluation, we developed the appropriate information through group brainstorming sessions and discussions.

2 Agenda

The workshop agenda followed the ATAM evaluation format. To capture goals and drivers, workshop participants brainstormed and conducted open discussions as a substitute for presentations. Based on prior, weekly meetings between IME and SEI, the SEI team prepared a *Component Product Line Scenario Handout Template* to guide the workshop discussion of PLS goals and drivers. The SEI group planned scenario development based on using the existing component capability models and applying the scenarios to evaluate those models against goals and drivers. IME ensured that the focus of the discussion examined the full breadth of the product line approach rather than specific models used in that approach. The review of the modeling approach was deferred until the end of the workshop and, due to time constraints, was further deferred to a subsequent weekly meeting of the IME/SEI group.

Workshop participants discussed the following:

1. Summarize the goals identified in the previous weekly exchanges and develop a joint IME/SEI list.
2. Review the approach by describing the basic scenario analysis workshop and its objective.
3. Explain the steps in scenario refinement and analysis by applying the basic structure of a Phase 1 ATAM Evaluation. (The goal of the workshop is to identify drivers of the IME PLS and brainstorm scenarios (targeting to identify 20) to refine elements of the strategy. The workshop participants will prioritize and consolidate the brainstormed scenarios into a short list for analysis.)
4. Examine the ecosystem to identify roles. Assign each role to one or more of the workshop participants to assume that perspective during the scenario analysis. (This step was not followed as planned.)
5. Discuss and refine drivers by creating a list of business goals and technical drivers (architectural drivers in ATAM evaluations).

6. Create an initial utility tree. (The drivers become entries in a tree where leaves are the specific scenarios that realize one or more drivers.)
7. Brainstorm, prioritize, and refine scenarios by developing a list of 15-25 scenarios contributed by each participant, prioritizing them, and combining them into a short list for further analysis.
8. Analyze the scenarios by following the template.
9. Present the component specification modeling approach by reviewing the modeling approach that captures the capability specifications. (This presentation was deferred to a weekly meeting.)
10. Discuss next steps.

3 Goals of Analysis

The goal of this scenario analysis workshop is to better understand the factors that influence a component product line approach to the acquisition of weapon systems for U.S. Army Aviation. The scenarios should address the following questions:

- How does the government ask for component products that are part of a product line? (These products are largely the same across different weapon systems but are not identical.)
- What is the relationship between the government and suppliers of a component product line or components instantiated from the product line?
- How does the government specify components for the development of a product line maintained by someone other than the government? (Given that components from the product line will be integrated as part of weapon system development, explain the changes this new approach fosters in the government-integrator role for acquiring weapon systems.)
- How does the government incentivize the supplier who produces the product line? (The benefit to the component supplier is a broader customer base among weapon system integrators. Suppliers may become “approved providers” and can more easily deliver components to those customers. The government is a customer of the weapon system integrator as well as the government that provides the specification to the supplier.)
- What cultural changes must occur for the government to take on this new role as the specifier of the component product line? (For weapon system integrations, the culture must change so that the government becomes the focus of the component marketplace. This change echoes the way consumers establish specifications for products in the commercial marketplace.)

The ARINC-655 Remote Data Concentrator (RDC) product line is an example that can illustrate these concepts.

- The government recognizes that these RDC products are built by component suppliers based on a published industry standard.

- The standard becomes the basis for a component specification with variations in function (required, optional and alternative). The government publishes a specification model that includes
 - variations in input streams (analog, digital and discrete information) from sensors on the airplane.
 - digitization and processing that varies based on feature sets need by specific users
 - protocols that communicate with on-board equipment according to output data bus, and data format.
- The goal of publishing the specification is to identify existing RDC product lines or request the creation of product lines that address the specification. The government also establishes test validation requirements that confirm products of the product line address capabilities within the specification when instantiated for a specific component with readiness for integration.
- The government also indicates the potential weapon system targets for components tailored and instantiated from industry product lines.
- The government uses established modeling techniques for the specification and uses these models to assess the conformance of supplier product lines to instantiate components for target systems.
- This product line approach engenders a major cultural change in acquisition. Instead of specifying a weapon system and expecting the integrator to provide a unique development approach for the system, the product line approach becomes the expected acquisition and development approach. Government specifications provide a marketplace for components, and integrators work with suppliers to obtain those components and integrate them as part of the weapon system being acquired.
- The government envisions a time when (1) integration can be reassigned to a new integrator and (2) alternative component suppliers can be identified to improve qualities such as affordability and time to field for a small number of aircraft manufacturers with variation across the space of actual RDCs.

Other questions will emerge and be addressed as the product line approach comes into common practice:

- The supplier-integrator arrangement must cover the costs to create integration-ready instances of the product line. Must these costs cover upgrades to the product line in response to changing weapon system needs?
- For the RDC and other product lines, the government must maintain a qualified supplier base. For the RDC, this supplier base may include as many as 12-20 RDC developers. For other product lines, especially those that are not based on industry standards, the supplier base will be small. Where no supplier base exists, how will the initial development be

funded? (A supplier of component products recoups costs of investment in the product line asset base. The benefit of this investment is the thrust of Scenario 4.)

- Who performs the modifications and upgrades to the product line? Is that a role of the original supplier, or can that role be assigned to an alternate supplier or be brought into the government? (This is the thrust of Scenario 5.)

To explore the PLS and approach, the output of the workshop will be applied to accomplish the following:

- Develop content and scoping for the initial report for the product line approach for system components.
- Explore the basic problems in achieving component product line specifications that will be used by the supplier community to develop component product lines.
- Create a specification template that includes the correct views and diagrams that suppliers can use to model and implement component product lines and deliver them to integrators for systems development.
- Determine the necessary steps to move from a current state to the desired state.
- Understand the scope and model approach to define the variation and feature model specifications needed for the component product line.
- Provide the TDD with the mechanisms and methods it can supply to the U.S. Army Program Executive Office-Aviation (PEO Aviation).

4 Drivers

The following are the official business drivers for the overall activity.

- Faster to Field
- Maintained Capability Overmatch
- Affordable Lifecycle Costs
- Increased Integration Efficiency (i.e., Rapid Integration)

Earlier discussions also identified the following concepts specific to the product line activity.

These are less business goals than underlying drivers (informal) for the activity:

- Address the needs of U.S. Army Aviation and its products within the scope of the product lines for its product components.
- Emphasize the role the government can play in producing a product beyond “stating need and directing money.”
- Identify concepts and methods to exploit commonality and optimize for the portfolio.
- Incentivize the identification, creation, and use of assets, and determine if they will integrate into and can be configured to work in several major weapon systems.
- Provide a value basis for product line management as strategic reuse.

From the technical perspective, the product line activity is driven by the following:

- TDD, the architect for cyber physical systems
- IME, the architect for the FoS² (e.g., product lines or collections of systems for common purpose)

Earlier discussions also identified the following concepts specific to the product line activity. These concepts are a mix of an architecture strategy and frameworks that potential users of the product lines apply. The Comprehensive Architecture Strategy (CAS) provides the principles that organizations should apply to establish architecture requirements at the enterprise (RefArch), FoS (ObjArch), and component specification (SysArch) levels. The CAS also guides how requirements are refined for a specific system.

The strategy should be applied to establish validation approaches that ensure that the architecture requirements are adequately addressed in system designs and implementation. The PLS addresses these levels of requirements through a set of sources and processes:

1. FACE³
2. FVL4 Architecture Framework (FAF)
3. Enterprise Architecture Framework (when implemented)
4. MOSA5 business and technical drivers
5. Defined engineering activities and artifacts applied in specifying, acquiring (Make/Buy/Mine/Commission), and using assets to produce products
6. Defined product lines and product line strategies that address recurrence of similar or identical software capabilities to be used across products/platforms
7. Specified product lines that enable suppliers to create or offer off-the-shelf solutions (How to create assets beyond specifications is not relevant.)
8. Exploiting the use of commercial off-the-shelf (COTS) or other existing product lines in major system platform development

5 Scenarios

The scenario brainstorming results are included in the appendix.

Workshop participants used the following templates for capturing and analyzing scenarios. During brainstorming, participants used the following three-part scenario description:

-
- ² A family is independently acquired.
 - ³ Future Airborne Capability Environment
 - ⁴ Future Vertical Lift
 - ⁵ modular open system approach

- **Stimulus**—What need is prompting the existence or actions in the scenario? (Example: Multiple suppliers can provide product lines of components.)
- **Environment**—What is the current state of the practice? (Example: Products are being developed in a cost-constrained environment.)
- **Result**—If the scenario is applied, what is the desired outcome? (Example: A marketplace exists for reusable components and is sustainable to achieve a higher return on investment.)

The following scenarios prioritize and combine a subset of the full scenario list in the appendix.

Scenario 1: Create a Marketplace for New/Novel Components

Summary of Intent

Create a marketplace of components that are designed to be reusable and that constitute product line assets. These assets for reuse are sustained and achieve greater enterprise value than single-use or custom-built components that are centrally controlled. The government recognizes the ability of product line providers to deliver on the specific needs of integrators. These providers do this by providing the capabilities and architecture for configurable component product lines that they build with system-specific components tailored to address unique uses by the platform/system integrator or an overarching product line supplier.

Source Scenarios

To create Scenario 1, we combined the following source scenarios from the brainstorming part of the workshop:

- Source Scenario 1: A marketplace exists for reusable components and is sustainable to achieve more for your dollar.
- Source Scenario 2: Create a marketplace for new/novel components.
- Source Scenario 3: The government recognizes the ability of product lines to deliver on need.

Business Drivers with Explanation or Rationale

Scenario 1 addresses the following business drivers with the Modular Open Systems Approach:

- **Faster to Field**—The product lines constitute major system components for the fleet of aircraft in the family of systems (FoS) and potentially for the enterprise. The product lines capture capabilities that are common to these systems, including variation points, allowing for tailoring to specific system needs. The scenario addresses the goal through the production of component implementation and the ability to integrate those components into the system with significant schedule savings, reduced risk, and continuous upgrades.

- **Affordable Lifecycle Costs**—When multiple systems share component development and sustainment, the costs of using and integrating those components decrease. Each program acquires components, sharing the costs in the same manner that off-the-shelf hardware costs are lower than those for custom-built hardware. Maintainers of individual systems must still understand the need for customization, including costs to customize from the product line and costs to integrate. These are still lower by at least 50% from the cost of developing and integrating unique, system-specific components [Nolan 2016]. However, these savings are realized under a PLS where a single organization controls the supply chain—establishing specifications; realizing architecture requirements; developing designs for components; and performing system implementation, integration, and test. The reality of weapon system acquisition—spread across multiple organizations—requires an approach that distributes these activities across the government specifier, the component developer, the weapon system acquirer, the weapon system integrator, and others involved in the ecosystem.

Technical or Architecture Requirements Addressed

The supplier developing the component product line must architect for the FoSs and the component product line itself. For the FoS that is the target that will integrate component product lines, the component supplier must address the architecture requirements and design of the family to permit integrations of the components instantiated from the component product line. The component product lines must address their specific architecture requirements in a way that reduces cost and schedule. The product line architecture must address the needs for commonality and variation, including functional and performance variations. The design must be tailorable to produce components instantiated from the product line; these components must address target system requirements with reduced cost (affordability) and time to field.

Analysis

Component product line modeling should accomplish more than other forms of documentation. If done correctly, modeling with analysis becomes a dynamic and responsive representation to address the technical requirements and support tailoring. These goals of modeling, including management of variation points, include tailoring for each specific system in the family. In this way, modeling of a component product line includes a description of how to exercise tailoring that can be performed to create a product line component instance for a specific weapon system.

Business decisions driven by models (e.g., how to meet specific quality attributes modeled as variations or what weapon-system-specific options or alternatives to select for an instance) can address interactions among the government, supplier, weapons system acquirer, and integrator. These decisions should provide business interoperability for tool exchange where, for example, Excel spreadsheets and a CAMEO Enterprise Architecture exchange information. Robust documentation practices are necessary to support understanding among organizations and close the distance between stakeholder organizations.

- **Government**—Define product line capability models that describe and capture form and function. These models cover the structure and functional elements that provide capability. The models themselves must also address form (i.e., which views are represented) and function (i.e., the meaning captured in those views). Models also address restrictions on component use, operational behavior and functionality, lifecycle and logistics, and management of variation in each of these areas across the component product line. Variations must also address potential deployment alternatives for the operating system, hardware, containerization, service orientation, and so on.
- **Supplier**—Apply product line capability models to support creating or mining from legacy to produce the component product line. The modeling capabilities and representations must support the following:
 - A component product line architecture definition that includes variation points
 - Implementation by the supplier that supports the integration needed for the weapon system environment
 - Product line instances of weapon-system-specific components created by the supplier or the integrator, where a business decision is made to provide the product line assets to the integrator for that purpose
- **Integrator**—Require information to understand potential component capabilities and assumptions about the system environment and requirements or constraints that pertain to the integration of the component.
 - Where the supplier creates a component instance, the integrator must receive assurance that component instances will be ready for integration and meet system requirements. The integrator must address all prerequisites defined for component use, including data for component configuration, addition of a required service or library, and creating wrappers or adapters.
 - Where the integrator creates the instance, the integrator must be provided with all information necessary to create that instance.
 - The integrator must be aware that full integration readiness may require, in addition to tailoring with the planned variation, completing an integration by extending the component instance to add an adapter between the component and the weapon systems.

The model representations for the component capability include the following:

- Functional architecture, operational activities, and behavior of state and event transactions
- Representation of features and variation points (functional and software) and feature sets for typical products defined by those points
- Generic hardware models with attributes and constraints
- Data architecture of communication protocols and configuration information
- If applicable, a model of the implementation environment for how the product would be delivered (actual, modeled, or both).

Layered Models

Models are layered in any of the following ways:

- Models are layered with different levels of detail (e.g., government, consortium, vendor/component specific).
- There are several commonly used and documented views of software and system architectures.
- Models vary in how they apply definitions. For example, the *Comprehensive Architecture Strategy* [Padilla 2018] proposes four levels of architecture that can each be documented in terms of one or more viewpoints:
 - Functional architecture—A method to document the functions or capabilities in a domain by what components do, the data they require or produce, and the behavior of the data needed to perform the function
 - Hardware architecture—The interconnection, interaction, and relationship of computing hardware components to support specific business or technical objectives
 - Software architecture—The relationship of software components and the way they interact to achieve specific business or technical objectives
 - Data architecture—The language and tools necessary to create, edit, and verify data models (A data model captures the semantic content of the information exchanged and captures the semantics of exposed interfaces.)
- Models are consistent with the quality attributes and business drivers of the organization. (These link back to the reference architecture requirements.)
- Models vary by their product line architecture, which can contain many component specifications, including options for sets of capabilities, functions, data, and information.
- Models are layered to address the granularity of the product lines, including utility and infrastructure capabilities that apply to multiple product lines.

The government provides capability models, including environmental constraints and/or applicable reference frameworks for deployment, to specify the product line the supplier will deliver. Multiple suppliers may offer solutions that comport to the product line requirements and address the minimum needed capabilities, creating a marketplace that integrators can use to select the product line or component instance that will best address their needs. This marketplace can occur in at least three ways.

1. The integrator can select an existing product in the product line.
2. The integrator can direct the supplier to deliver a component instance that is configured from the component product line.
3. The integrator can select a product line package that allows it to establish its own configured component instance needed by the target system.

These alternatives achieve the business goals of affordability in producing system-specific components through the product line. Each alternative also provides a clear path for achieving the technical requirements by using models that inform the supplier, developer/implementer, and integrator in making their downstream architecture, design, and implementation decisions. Quality attributes are communicated by the weapon systems acquirer. The integrator evaluates the selection of products in the marketplace to determine which one best responds to the weapon system quality attribute requirements, with possible tradeoffs, to best address attributes needed by the acquirer.

Applying a component product line supports testability through the repeated use of the same starting point for each component—the component product line. Previous instances have undergone supplier testing and have a pedigree of integrator use, testing, and qualification. On the quantitative side, both the supplier and integrator can track product metrics (e.g., frequency of use, cost of use, repair history, and user acceptance) of products built using the component product line. Metrics can also include a dashboard of performance specifications, including run-time size, timing, bandwidth requirements, and other subjective measures.

Risks related to meeting goals and addressing technical requirements include the following:

- **Attribute Concerns**—If modeling capabilities is strictly functional without considering broader architecture requirements, the product line may not be sufficiently tailorable to specific system needs and will not be adopted.
- **Modeling Decisions and Reasoning**—The government and supplier must sufficiently understand the scope of use of the components instantiated from the product line. If the models and implementation are too narrow in scope, they will not provide sufficient benefits, requiring significant effort from the integrator to use instantiated components. If the product line scope is too broad, it may be too costly to develop or may not be able to address target system specifics. Given the breadth of coverage, variation will require too much customization or unique development to account for this breadth.

Scenario 2: Establish Acquisition Freedom of Action to Re-Compete

Summary of Intent

The component PLS gives acquisition authorities greater freedom of action in acquisition. It should support the ability to acquire systems and system components from a broader set of integrators or suppliers. It should also support the ability of the acquirer to re-compete existing developments from competitive sources as a means to increase affordability, performance, and quality as well as decrease time to field.

Source Scenarios

To create Scenario 2, we combined the following source scenarios from the brainstorming part of the workshop:

- Source Scenario 3: Use the adaptive acquisition framework effectively.
- Source Scenario 7: Provide acquisition freedom of action to re-compete the weapon system integrator or supplier.
- Source Scenario 15: Provide current and comprehensive documentation system so “outsider” can join.

Business Drivers with Explanation or Rationale

Scenario 2 primarily addresses the business goal of affordability. By making the integrator and supplier roles open to greater competition, contractors are incentivized to deliver solutions that provide lower acquisition costs. This innovation can also address the business driver of time to field. A competing integrator may offer improvements in fielding new capabilities based on the capabilities that are open to competition. A supplier may offer a wider set of features that can be adapted and tailored for upgrades rather than rely on custom developments for the individual system.

Technical or Architecture Requirements Addressed

Scenario 2 addresses the primary technical driver for an architecture that supports the FoS. A to-be-published capability model will link to the FoS architecture that will integrate components instantiated from the product line.

Analysis

The component PLS must address the technical requirements that support specification of component product lines or acquisition of components from the product line supplier. The implementation approaches must also support subsequent tailoring of a component from the product line for each specific weapon system in a family. In this scenario, freedom of action in acquisition is supported (1) by enhanced competition from the supplier community for component product lines and (2) from the integrator original equipment manufacturers (OEMs) to develop and integrate solutions based on a product line’s components. The business and modeling decisions address the government, supplier and integrator sides:

- **Government**—Incentivize suppliers to build product line capability models that capture functionality, behavior, and variation to meet the needs of systems across the family.
- **Supplier**—Work with the government to deliver solutions that provide flexibility in acquisition from OEMs. Suppliers must understand the scope, technology evolution, and appropriate

ate acquisition approaches to apply in building solutions for the product line capability models. They must realize that they are competing with other suppliers to best address government needs over the FoS and anticipated changes and upgrades.

- **Integrators**—Perform instantiation of components from the product or rely on the supplier to perform that role. Acquisition freedom allows the government to support either the supplier or integrator in that role based on specific product line characteristics, data rights, and schedule. The acquisition must include time for integration for component product line understanding to assure that component instances will meet system requirements.

An advantage of this strategy is being able to define and update the product line capability as often and as freely as possible. Components of a system are not static and neither are the components that should be available to the market to support the scope of the FoS. The capability specification will be continuously updated to reflect changes in technology, threat, mission, and system properties. The specification helps when identifying the availability of a product line, discoverability of new opportunities, and usability by integrators. These advantages require an environment where capabilities are specified and modeled for ease of use and understandability by both the supplier and integrator.

The government that models capability specifications for the component product line must assure that their models contain sufficient detail to generate—manually or automatically—documentation for specific components based on a system context. The models must enable feature selection for function, behavior, resource constraints, safety, security, and deployment considerations. The initial capability specification does not need to address all these selections, but the ease of updating and releasing new versions of a specification supports rapid evolution and improvement. This quality is a benefit of the capability model approach that a component library can never meet. It also puts a burden of competition on potential suppliers to be able to rapidly respond to the evolving nature of the component product line specification.

Risks to Meeting Goals and Addressing Technical Requirements

The government risks the ability to identify suppliers unless it takes an incremental approach to releasing component product line specifications. The suppliers should provide input to shape the product line specification based on existing solutions, even those not yet on the market. Where the product line is based on an industry or government standard, suppliers should be allowed to comment on specific tailoring, properties, or other characteristics of the components that will be instantiated from the product line.

Scenario 3: Create or Increase Warfighting Effectiveness

Summary of Intent

Programs have a continuous need to deliver new mission capability to the field through faster upgrades and regular deliver; however, these actions take too long because of accreditation and acquisition delays. Also, delivering upgrades is unpredictable because of unanticipated capability changes. The PLS can create or increase warfighting effectiveness by addressing these needs. It should support the fielding of systems that are capable of incremental updates. Systems fielded through integration of components can be upgraded quickly as revisions to those components occur; changes to a component from a product line will be tested to assure conformance and prevent side effects. In areas that are safety and security constrained, the product line approach should provide rapid upgrades to address new threats. Integrators will be provided with continuous integration and continuous delivery.

A related consideration is delivering operational systems software that is the same as software that is used in training systems. The PLS should deliver a component product line with variants that can be integrated simultaneously in the operational and training environments. The PLS should result in trainers and operational systems users seeing the same interactions with synchronized upgrades.

Source Scenarios

To create Scenario 3, we combined the following source scenarios from the brainstorming part of the workshop:

- Source Scenario 5: Create or increase warfighting effectiveness.
- Source Scenario 9: Enable incremental delivery of capability.
- Source Scenario 14: Use the same software in training systems and operational systems.

Business Drivers with Explanation or Rationale

The main business driver for Scenario 3 is to Maintained Capability Overmatch. In the current environment, system improvement and upgrade must go through the entire acquisition cycle. Identifying the potential need for these upgrades can support the customer's need to sustain overmatching performance. Where the requirements have been allocated to components, the need to maintain overmatch of capability can be addressed with updates to the component product line specification. Suppliers can sustain their product lines in accordance with the specification updates and continue to support integrator needs to deliver the overmatch capabilities. A goal of suppliers is to address the need for rapid upgrade and increasing warfighter effectiveness. This benefit is associated specifically with Scenario 2 (Establish Acquisition Freedom of Action to Re-Compete) and Scenario 5 (Sustain the Product Line and Weapon Systems that Integration Components). A standard component from a library cannot be effective without the full acquisition lifecycle applied to the government furnished information (GFI) component.

Technical or Architecture Requirements Addressed

Scenario 3 addresses the primary technical driver for an architecture that supports the FoS. A to-be-published capability model will provide a range of alternatives and possibly anticipate the needs of future upgrades. A prebuilt component cannot address all needs, but the specification of a product line will inform the supplier of the desired extensibility to meet the need for an upgrade.

Potential suppliers must consult with the government to determine the schedule for these upgrades and construct the product line architecture with necessary extensions, options, or alternatives to handle those changes in the future. Suppliers do not need to provide solutions for those upgrades, but they should be able to model and implement those upgrades when they move to the current-need status. This approach enables suppliers to innovate and anticipate new capabilities for the product line, resulting in outpacing the threat.

A specific approach to achieving overmatch is to require component capabilities that can be achieved through a product line that addresses operational and training needs. Inadequate or unavailable training might result in a delivered system that cannot be operated optimally (e.g., use the latest upgrades). Keeping the training and operation synchronized is another architecture requirement that this scenario must address.

Analysis

The component PLS must address the technical requirements for current overmatch needs. But as threats, technology, and computing resources evolve, achieving overmatch will also rapidly evolve. In some cases, this evolution maybe anticipated, but in other warfighting environments, the specific overmatch needs cannot be adequately anticipated. The business and modeling decisions address the government, supplier, and integrator sides:

- **Government**—Require suppliers to build product line capability models that not only capture functionality, behavior, and variation to meet current system needs across the family, but define architecture requirements for extensibility and maintainability that can (1) address change with minimum side effects and (2) rapidly improve warfighting capability.
- **Supplier**—Work with the government to understand current warfighting needs and the anticipated improvement to maintain overmatch across a forward-looking timeframe. Suppliers typically have the most thorough understanding of the scope, technology evolution, and appropriate acquisition approaches to build solutions that achieve overmatch and optimal warfighting capability. They realize that they are competing with other suppliers to best address government needs to improve warfighting capability. They will deliver on overmatch requirements through anticipated changes and upgrades, or through unanticipated changes that can be addressed through extensible solution architectures for the product line.
- **Integrator**—Perform instantiation of components from the product or rely on the supplier to perform that role. Scenario 3 can help when the OEM is not the focus of acquisition for enhanced warfighting capability or maintaining overmatch. This role may be achieved through

the component product line. For example, the scenario frees the OEM to address other areas of maintenance in optimizing overall system performance or safety.

The component product line specification continually evolves and can be extended. Its initial creation should be defined by this evolutionary need. Also, specific extensions—even those that are not specifically anticipated—can be addressed in the product line architecture and implementation. The integrator can then easily enhance the warfighting capability of the system by integrating new components from the product line rather than building them for the specific system. The entire FoS benefits from the overmatch capabilities available through the product line.

In parallel to upgrading systems through integration, operational systems provide operational feedback to the component product line capability model and resulting supplier product lines. The FoS provides much operational data that documents component needs, whether for defect repair, optimization, or closing capability gaps. These needs are addressed through changes or enhancements to the capability models; the models are then delivered to the suppliers as part of a continuous improvement cycle. Integrators benefit from sharing needs across the FoS, even when the specific system of a specific integrator did not encounter the need for change.

Potential features, options, alternatives, and upgrades can be captured in a scenario list for initial modeling. Models may not provide all specific capabilities in an initial release but can anticipate changes and then activate them in later releases. Similarly, supplier product line solutions will not implement all potential features or variations; however, by understanding the scenario list, they can construct a product line architecture capability to address downstream changes and upgrades. The direct input to market of such government needs greatly benefits warfighting effectiveness:

- It shortens the cycle time for delivering upgrades by improving the delivery of those capabilities through competition.
- It reduces the integration burden by delivering components based on a consistent product line architecture.

Risks

A major risk to the success of Scenario 3 is overburdening the scenario list with too many options, alternatives, and variations. While modeling for the scope of the scenario is not a significant risk, without well-planned prioritization, the component product line may never achieve the desired capability for initial prioritization. This risk can result in delays to delivery, costs to sustain too broad a scope, and the sacrificing of quality for quantity of capability. The ecosystem of government, suppliers, and integrators should be involved in prioritizing the scenario list and establishing timelines to address continuous integration of new capabilities and achieving the overmatch goal.

Scenario 4: Reap the Benefits from Economies of Scale

Summary of Intent

A sustainable product line must be (1) affordable to users of its products (i.e., the integration-ready components) and (2) profitable to the supplier. Affordability is directly related to cost and value.

- Cost includes development of the component product line—both the capability specification on the government side and the component product line asset base on the supplier side. These costs should be one criterion in evaluating the feasibility of applying a product line approach for the components in the proposed product line.
- Value to the government is determined by achieving improvements in affordability of weapon systems and other goals supported by a proposed product line specification, product line architecture, or the resulting components of the product line.

Using the PLS makes each weapon system more affordable by enabling strategic reuse of components across a family of weapon systems.

Source Scenarios

To create Scenario 4, we combined the following source scenarios from the brainstorming part of the workshop:

- Source Scenario 17: Apply a cost model for hardware, infrastructure, and software [SEI 2005].
- Source Scenario 18: Reap the benefits from economies of scale.

Business Drivers with Explanation or Rationale

The primary business driver for Scenario 4 is Affordable Lifecycle Costs. In component product lines, capabilities captured in the product line specification can be met through a component from the product line that is integrated as part of the acquired weapon system. Current acquisition may reuse components from previous developments in a new weapon system, but those components require extensive and often unanticipated tailoring. Under the PLS, a component product line specification addresses the common requirements and anticipated changes that will be required in the new weapon systems. The variations (i.e., options, alternatives) for those new systems and guidance to suppliers for delivering a product line architecture and other assets are essential in creating the weapon-system-specific component for integration. The product line achieves affordability by sharing those up-front engineering costs across all potential users of the component product line.

Technical or Architecture Requirements Addressed

Scenario 4 addresses the primary technical driver for an architecture that supports the FoS by determining costs in the following categories:

- Government—To create the product line specification
- Suppliers—To create the component asset base (e.g., product line architecture including hardware, software, data models) that must be recouped through use of components of the product line
- Integrators—To identify and qualify a component for use
 - For components to be instantiated from a product line, these costs include selecting the component (i.e., costs associated with understanding and evaluating the choice among competing product lines), licensing component use, tailoring the component or contracting with suppliers to tailor the component, and changing the weapon system to support component integration.
 - For existing components that meet specific feature sets, there may be costs associated with developing or adding capabilities not covered in the feature set of that component.

The cost model should provide estimates for building a component outside the product line or provide factors to consider as a basis of estimating the costs to tailor a legacy component not built for use with this specific weapon system.

The resulting analysis must account for the potential economies of scale (the reduced costs using a component based on the number of weapon systems planning to use components from the product line). Such factors as component sustainment or replacement should be shared across the user base.

Analysis

Analysis includes the following activities:

- Gather information, and structure the argument. Example information includes costs of modeling capabilities, deriving the product line owned by supplier (or as GFI), and (3) using the product line by the supplier to tailor (or as GFI by the integrator).
- Consider the environment. Factor in (1) development, reuse, and sustainment costs that may not be easily determined or that may be estimated, and (2) the large number of delivered systems that might need similar capabilities and interfaces.
- Analyze the results. For example, multiple instances of components from multiple product lines in the FoS deliver $x\%$ improvement in development and sustainment costs. This analysis can predict costs for using product lines across the lifecycle that may be over 20 years to within $x\%$ of accuracy.

We consider the following stakeholders in Scenario 4:

- Government/Product Line Clearinghouse⁶
 - Costs to create the component product line specification are known (if the specification is complete) or may be estimated.
 - Supplier costs to develop core assets are estimated or captured from bids. The configuration of each asset (e.g., module, component, system) is priced.
 - Configurations of these assets use the appropriate variants created to estimate costs.
 - Reusable elements have an adjusted cost.
 - Administrative costs of the product line organization that support the product line are added to the formula.
 - The total cost is computed with input from the suppliers.
 - Several different configurations of the products (i.e., different product members) can be computed to determine the optimal product line.
- Supplier/Product Developer
 - Costs of unique pieces of the product are provided to the product line manager for the formula.
 - Supplier organizational costs are provided to the product line manager for the formula.
- Integrator
 - Costs are factored in to evaluate the marketplace offerings and make tradeoff decisions to select a product line. (These are the same for selecting among existing products in the tailored product selection.)
 - Integrator costs are considered to adapt a product line component for integration if the integrator is performing this role. This adaptation may include building adapters or wrappers for the component. The integrator may also test the component or repeat supplier tests in the integrator's environment.
 - Costs are considered to acquire an integration-ready component from a supplier that performs the instantiation.
 - Costs are considered to modify the already-designed or built weapon system to perform integration of the component. These costs may be associated with adapting the component or implementing more substantial changes required to modify parts of a weapon system that are affected by the component (e.g., addressing side effects to safety, security).

⁶ This may be a single stakeholder organization, or an organization and clearinghouse for the product line may be separate organizations.

Risks to Meeting Goals and Addressing Technical Requirements

A primary risk to achieving affordability is anticipating potential weapon systems that will use the product line as a source for the specific component. If the desired component is from a product line with limited use, the integrator may be required to pay all development and sustainment costs, or the supplier will assume these costs. Insufficient credible competition in a product line that has few users might affect affordability; there is little value for a supplier to sustain a product line for a small number of users.

Scenario 5: Sustain the Product Line and Weapon Systems that Integrate Components

Summary of Intent

For decades, the Achilles' heel of software product lines has been long-term sustainment of product line assets, evolution of the product line, and support to users of product line products. These concerns exist for industrial and government product line developments and systematic software reuse in general. Planning must include sustainment through the lifetime of the product line, not just for the creation and initial use of the product line products. Sustainment includes planning for issues such as the following:

- Maintaining the product line specification (government)
- Maintaining the product line core assets (suppliers)
- Supporting the marketplace of component product lines (product line clearinghouse or specifier)
- Assuring that the integrator adheres to the PLS by working through the marketplace for new, upgraded, or replacement components

Scenario 5 also includes a sustainment process that determines (1) which updates should be made to the product line or individual products, (2) how to support integrators using product line components, and (3) when to retire a product line.

Source Scenarios

To create Scenario 5, we combined the following source scenarios from the brainstorming part of the workshop:

- Source Scenario 12: Increase reliability and maintainability.
- Source Scenario 13: Move sustainment of products to the provider's side.

Business Drivers with Explanation or Rationale

The two primary business drivers for Scenario 5 are Affordable Lifecycle Costs and Maintained Capability Overmatch. A continuous review of the use of the components instantiated from the product line should be conducted. This review determines which capabilities require continued support, which require changes and updates, and which should be retired (i.e., never used); the review also determines which new capabilities should be added. Sustainment of the capabilities supports viability of the product line for integrator use and the supplier role in maintaining currency of the product line.

The need for overmatch can also be supported by monitoring and addressing the capability specification. As threats evolve, new technology is developed and system interactions (e.g., the need for enhanced interoperability) are changed, and the product line must respond. The costs of upgrades can be shared across users of the FoS and therefore affect affordability.

Technical or Architecture Requirements Addressed

Suppliers must constantly assess the evolution of hardware, including hardware associated with networks, processors, and bus technology. The component product line specification may not change, but this evolution can be centrally analyzed, with the analysis provided to existing or emerging suppliers. The goal is to anticipate technology direction and assure that the product line will support hardware evolution.

Analysis

Scenario 5 is predicated on the need to share maintenance across users of product line components to lower error reports, increase affordability, and maintain capability overmatch. With current weapon system approaches, each final weapon system product must be maintained individually. Component use must be handled on a one-on-one basis between the weapons system and the component supplier. A properly implemented component product line sustainment scenario results in suppliers improving reliability and maintainability through planning for multiple uses of the core asset for a variety of delivered weapon systems. Defect reports that go back to suppliers should decrease by at least 50% and ease of upgrade should increase by a similar reduction in cost. This decrease is possible due to component use across multiple weapon systems. Feature addition or enhancement goes back through the component specifier and then is addressed by suppliers.

An additional aspect of this scenario is eliminating vendor lock on common software. The longer a product line specification remains viable, the greater the likelihood that new suppliers will enter the marketplace. In the current environment, the government acquires products, and it must sustain them or contract with a sustainment vendor or organization. With Scenario 5, sustainment can be performed by a consortium or other organization as a provider of the product line.

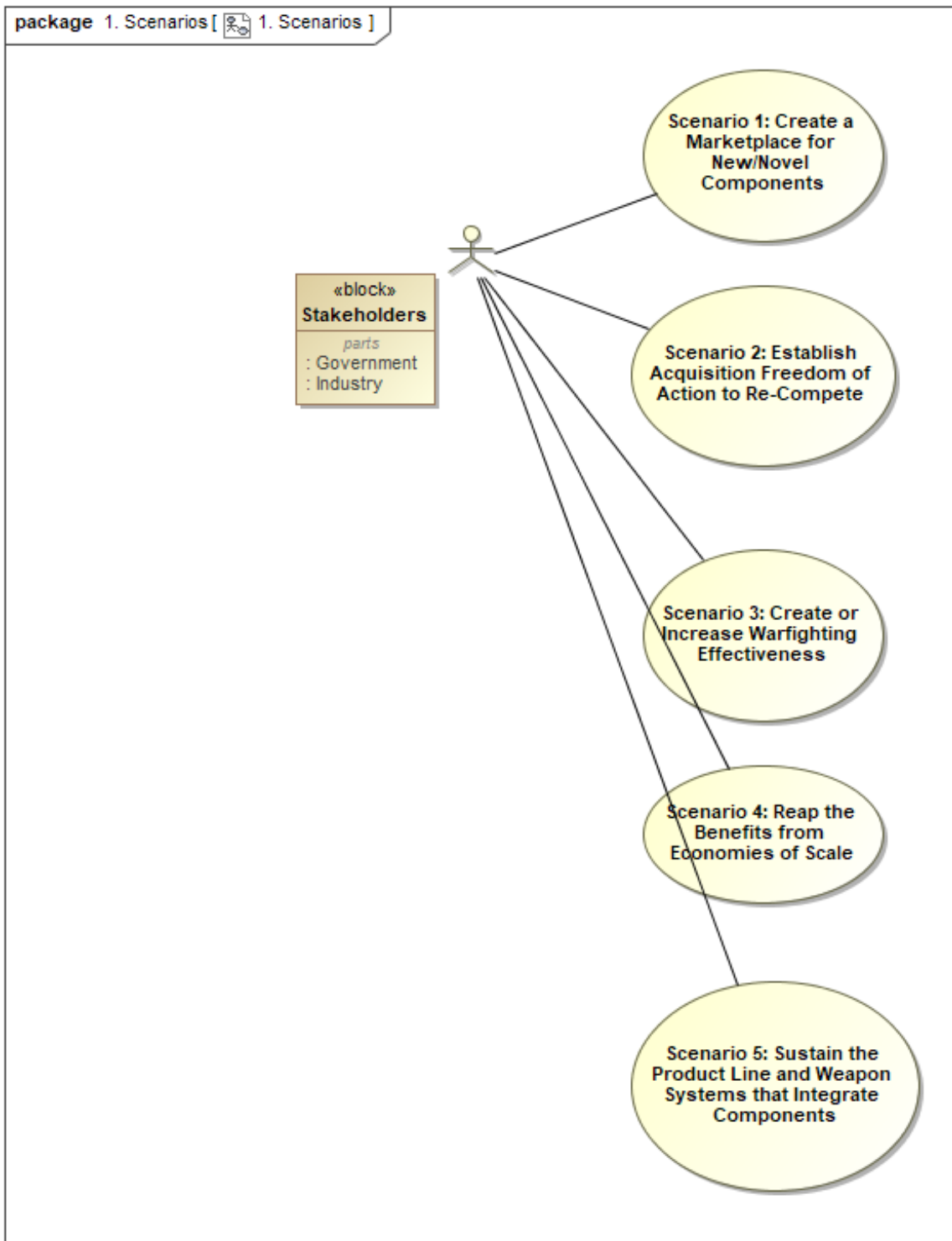
The product line clearinghouse also factors into this scenario. The government specifies the capabilities for product lines, and suppliers model and build components to these specifications. However, the specification and modeling organizations may not be suited to maintain the integrity of product lines over time in terms of continuous testing, certification, and use by the community of weapon system integrators. The specification organization may choose not to work directly with the marketplace or provide an intermediary role in working among suppliers and integrators. Once a product line is in place, these roles can be handed off to the clearinghouse for long-term sustainment of the product line. To determine the best way to address the needs of the supplier and users, the clearinghouse assesses the use of product line assets, technology directions, changing threats, use of products, and marketplace drivers. The clearinghouse then addresses changes needed to specifications and improvements (or changes suppliers must address), or it may provide support to components users.

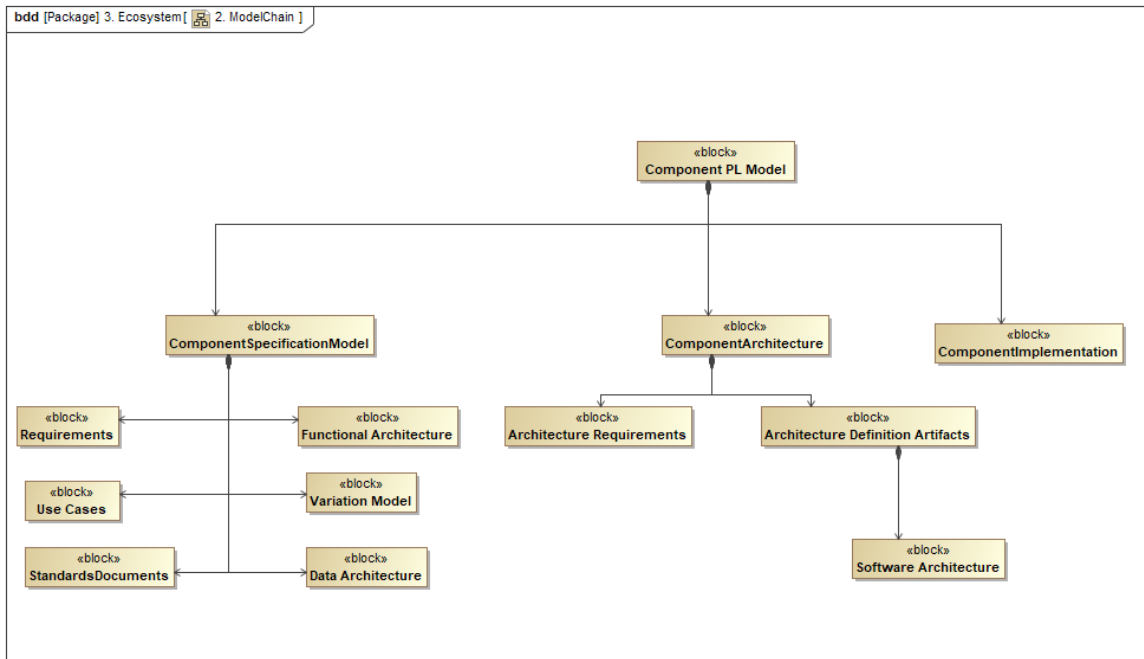
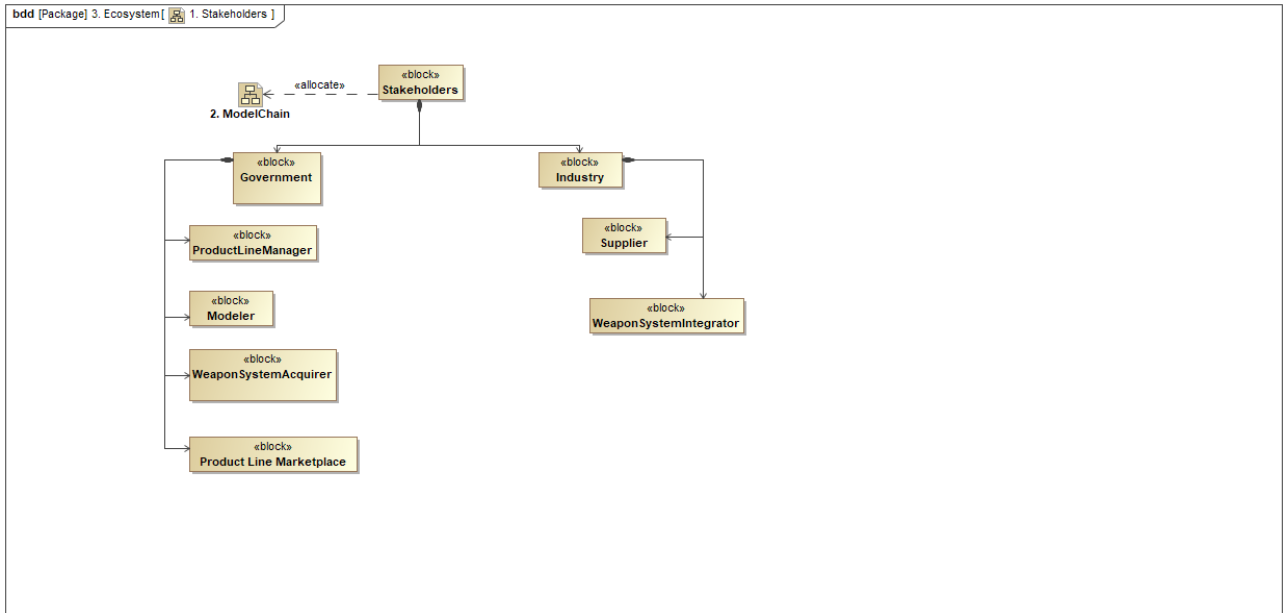
Risks to Meeting Goals and Addressing Technical Requirements

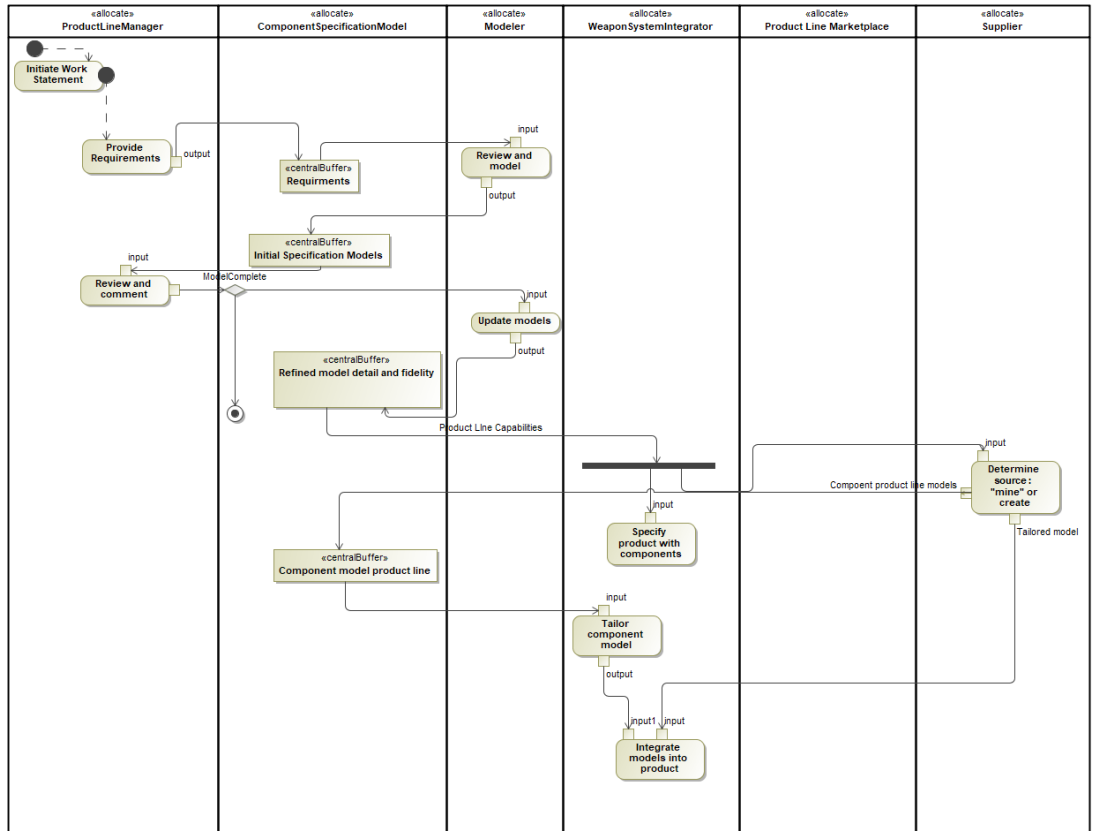
A clear risk is sustaining the product line beyond its expiration date. At some point, the existing specification or product line assets will no longer address user needs and must undergo a major overhaul. At that point, the product line may be ready for retirement and replacement.

6 Analysis (Draft)

This section presents a workflow description built around the scenarios. This workflow will be refined in parallel with the production of the three reports (Strategy, Modeling, and Governance) with a final version as part of the Governance Report.







Results and Lessons Learned

The analysis workshop identified the following recommendations and lessons:

1. Further refine an adaptation of the ATAM evaluation process. The SEI assumed that scenarios should be evaluated with respect to an artifact—in this case, the current component specification models. The IME group emphasized the need to explore scenarios that were not specific to a given modeling approach.
2. Prepare the agenda and agree to the focus of the evaluation in advance.
3. Assure the meeting takes place in a location that provides visitor access to Wi-Fi. In the workshop, the lack of Wi-Fi connections made it difficult to share screens. SEI participants did not have access to the Internet and could not provide updates to the slides distributed before the workshop.
4. Ensure Wi-Fi adequate access for future virtual meetings.

Appendix Source Scenarios

Fully analyzed scenarios appear in bold text in the following list.

1. A marketplace exists for reusable components and is sustainable to achieve more for your dollar.
2. **Create a marketplace for new/novel components.**
3. Use the adaptive acquisition framework effectively.
4. Allow the government to specify common components.
5. **Create or increase warfighting effectiveness.**
6. Utilize COTS products.
7. **Establish acquisition freedom of action to recompute.**
8. Create a pipeline for continuous delivery.
9. Enable incremental delivery of capability.
10. Separate air vehicle and mission avionics development.
11. The government recognizes the ability of product lines to deliver on need.
12. Increase reliability and maintainability.
13. Move sustainment of products to the provider's side. (Refined as: **Sustain the product line and weapon systems that integrate components**)
14. Use the same software in training systems and operational systems.
15. Provide current and comprehensive documentation system so “outsider” can join.

16. Introduce state of technology into Legacy, state of practice.
17. Apply a cost model for hardware, infrastructure, and software (SIMPLE).
- 18. Reap the benefits from economies of scale.**

References

[Nolan 2016]

Nolan, Andy; Pickard, Andrew, Fisher, Steve; & Beasley, Richard. A Case for Product Lines. Pages 645-660. In *Proceedings of the 26th Annual INCOSE International Symposium (IS 2016)*. September 2016. <http://www.doi.org/10.1002/j.2334-5837.2016.00184.x>

[Padilla 2018]

Padilla, Marcell. Comprehensive Architecture Strategy (CAS). U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) Aviation Development Directorate (ADD). July 12, 2018. <https://www.dsp.dla.mil/Portals/26/Documents/Publications/Conferences/2018/DSP%20Workshop%20July2018/DSPWorkshop-Day4-180712/DSPWorkshop-5Padilla-180712.pdf?ver=2018-08-01-150712-570>