Employing the Second Generation Software Product-line for Live Training Transformation

Jeremy T. Lanman, Brian E. Kemper
U.S. Army PEO STRI
Orlando, FL
{jeremy.lanman,brian.e.kemper}@us.army.mil

Jorge Rivera
General Dynamics C4 Systems
Orlando, FL
jorge.rivera@gdc4s.com

Charles W. Krueger
BigLever Software, Inc.
Austin, TX
ckrueger@biglever.com

ABSTRACT

The Project Manager Training Devices (PM TRADE) has been a leader within the Program Executive Office Simulation, Training and Instrumentation (PEO STRI) and the Army in advancing the concept of a common, component-based software product-line through the introduction and development of the Common Training Instrumentation Architecture (CTIA) and Live Training Transformation (LT2) Family of Training Systems. While the traditional software product-line paradigm has proven successful in reducing stove-pipe development and the initial cost of deploying new members of the LT2 family, there are inherent complexity challenges during maintenance and evolution due to baseline divergence of the reusable software components that have been downloaded and tailored for the different product configurations. With each new product team that creates a new baseline, the cost and effort grows exponentially for merging software features and patches from the products back into the core assets and then out to other members of the product-line, leading to high cost and unmanageable complexity.

The Consolidated Product-line Management (CPM) construct incorporates a new Second Generation Software Product-line (2G SPL) paradigm that breaks divergence, and enables an automated production-line process of generating one or more products in the LT2 software product-line from a common set of core assets and feature profiles. Rather than each product team customizing a new configuration baseline, resulting in exponential complexity growth, the CPM solution builds products using innovative configuration and variation management tools plus automated production processes. This eliminates uncontrolled growth in complexity management and ultimately reduces sustainment and operations maintenance cost, and allows this saved time, cost and effort to be invested instead into innovations in the LT2 product-line.

This paper will describe the incremental approach for deploying the CPM 2G SPL and the activities that enable the Army's LT2 strategy to; 1) protect the investment in the existing LT2 core assets, 2) consolidate the LT2 product baselines using variation management and an integrated, feature-driven software product-line factory, and 3) innovate using state-of-the-art automated software tools and processes, management dashboards, and software product-line technology.

ABOUT THE AUTHORS

Dr. Jeremy T. Lanman is the lead systems architect for the U.S. Army PEO STRI Common Training Instrumentation Architecture (CTIA) and Consolidated Product-line Management (CPM) construct supporting the Army's Live Training Transformation Family of Training Systems. His professional experience includes 10 years of DoD acquisition and systems engineering of military modeling and simulation, and training systems. His research interests include service-oriented architectures, live, virtual, and constructive integration and analysis, and distributed computing. Dr. Lanman received his BS in Computer Science from Butler University, MS in Software Engineering from Embry-Riddle Aeronautical University, and PhD in Modeling and Simulation from the University of Central Florida.

Mr. Brian E. Kemper is the Live Training Transformation (LT2) Chief Engineer for the United States Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) in PM TRADE. Mr. Kemper received his undergraduate degree in Electrical Engineering from the University of Central Florida. Mr. Kemper has 25 years of systems engineering experience in both industry and civil service, supporting DoD military, training and simulation, and NASA design and development initiatives.

Mr. Jorge Rivera is currently working for General Dynamics C4 Systems out of the Orlando facility leading live training efforts and supporting the 2nd Generation Product-line instantiation under the CPM contract. His prior experience includes 25 years of DoD Acquisition service with over 15 years of those in the live training domain. As the Assistant Project Manager (APM) LT2, Mr. Rivera championed the LT2 product-line and managed the CTIA & FASIT efforts. He earned his B.S. in Electrical Engineering (EE) from the University of Puerto Rico in 1983 and his M.S. in EE from Fairleigh Dickinson University, NJ in 1987.

Dr. Charles W. Krueger is the founder and CEO of BigLever Software, the leading provider of systems and software product-line (SPL) framework, tools and services. He moderates the SoftwareProductLines.com website and is a thought leader in the SPL field, with 20 years of experience in software development practice and more than 40 articles, columns, book chapters, and conference session presentations. Dr. Krueger has proven expertise in leading commercial product-line development teams, and helping companies establish some of the industry's most notable SPL practices such as General Motors, Lockheed Martin, General Dynamics and IKERLAN, as well as Software Product Line Hall of Fame inductees LSI Logic, HomeAway and Salion. He received his PhD in computer science from Carnegie Mellon University.

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INTRODUCTION

The United States Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI) is in the business of training Soldiers and growing leaders by providing responsive, interoperable simulation, training, and testing solutions and acquisition services for the Warfighter and the Nation. Within its training and testing capabilities portfolio there is a dynamic set of Live, Virtual, and Constructive, embedded and interoperable products that are fielded and used throughout the world. Within the Live Training Domain exists the Live Training Transformation (LT2) Product-line. This product-line consists of open architectures, common components, standards, processes, policies, governance, documentation, and other core assets that make up the common approach and frameworks for developing live training systems. This paper provides an overview of some of the latest advancements being made to the LT2 Product-line by describing the incremental approach for deploying the Consolidated Product-line Management (CPM) Second Generation Software Product-line (2G SPL) that will consolidate the LT2 product baselines using variation management and an integrated, feature-driven software product-line factory and innovate using state-of-the-art automated software tools and processes, management dashboards, and software product-line technology all while protecting the investment in the existing LT2 core assets,

Prior to the implementation of the LT2 Product-line, live training systems and devices consisted largely of products developed separately by a variety of different manufacturers to comply with disparate requirement sets designed and implemented without a common framework. Commonality was not attempted and interoperability among systems was rare, difficult, and costly to achieve. Configuration changes to both hardware and software were most often performed on-site as part of the sustainment effort making configuration control virtually impossible.

The LT2 vision is to create a family of live training systems using a common architecture with common data, standards, processes and components. This facilitates the development of new products and ensures that products across the LT2 Product-line can communicate and interoperate. The LT2 Product-line makes use of plug and play components and applications that are common between products, and permits changes, upgrades and fixes developed for one product to be applied to others. This concept provides the inherent logistics support benefits that derive from commonality, standardization and interoperability including the reduction of total life cycle costs (Rivera, 2008; Samper, 2007)

Each Product Manager of Project Manager Training Devices (PM TRADE) has the mission of managing the configuration baseline of systems throughout the total life cycle to ensure the integrity of the product-line and to ensure systems remain relevant to evolving requirements, changing technology and other emerging systems. The process by which PM TRADE manages products must be deliberate, disciplined and coordinated in order to maximize use of common assets, components and subsystems in the development of new products, synchronize the production of products to gain efficiencies, enable supporting efforts, and to maintain seamless interoperability between components, products and systems.

PM TRADE has established the CPM approach to take the LT2 product-line to the next level to maximize the commonality, reuse and interoperability of the product-lines while meeting training goals (U.S. Army, 2008). CPM provides the means to:

- Protect the significant live training investment
- Support development, production and sustainment of LT2 products
- Realize the Return on Investment (ROI) and sustainment cost avoidance objectives
- Enable managers to maintain visibility and provide enhanced configuration control of their systems
- Ease insertion of new technology
- Efficiently execute new IA mandates
- Avoid duplications of efforts
- Support Army vision to be joint and train in an Live, Virtual & Constructive (LVC) environment

PRODUCT-LINE STRATEGY BACKGROUND

Systems and software product-line (SPL) engineering is an innovative approach that enables organizations to develop, deliver and evolve an entire product-line portfolio, through each stage of the development lifecycle, with much higher degrees of efficiency than has been possible before (Clements, 2002)

Software Product-line Application

Companies across a diverse range of industries – including aerospace, defense, automotive, medical, consumer electronics, computer systems, alternative energy, telecommunications, semiconductor fabrication, software applications, computer games, e-commerce and industrial automation systems – have successfully employed the SPL approach to more efficiently extend and evolve their product-line portfolios, achieving new levels of competitiveness and profitability.

As suggested in Figure 1 below, the characteristic that distinguishes the SPL approach from previous efforts is when an organization invests in a means of production that enables it to efficiently create a product-line of similar systems from a consolidated set of soft assets such as requirements, designs, source code and test cases. Manufacturers of hard goods have long employed analogous engineering methods to create a product-line of similar systems using a common factory that assembles and configures parts from a supply chain designed to be reused across the product-line (Northrop, 2009)

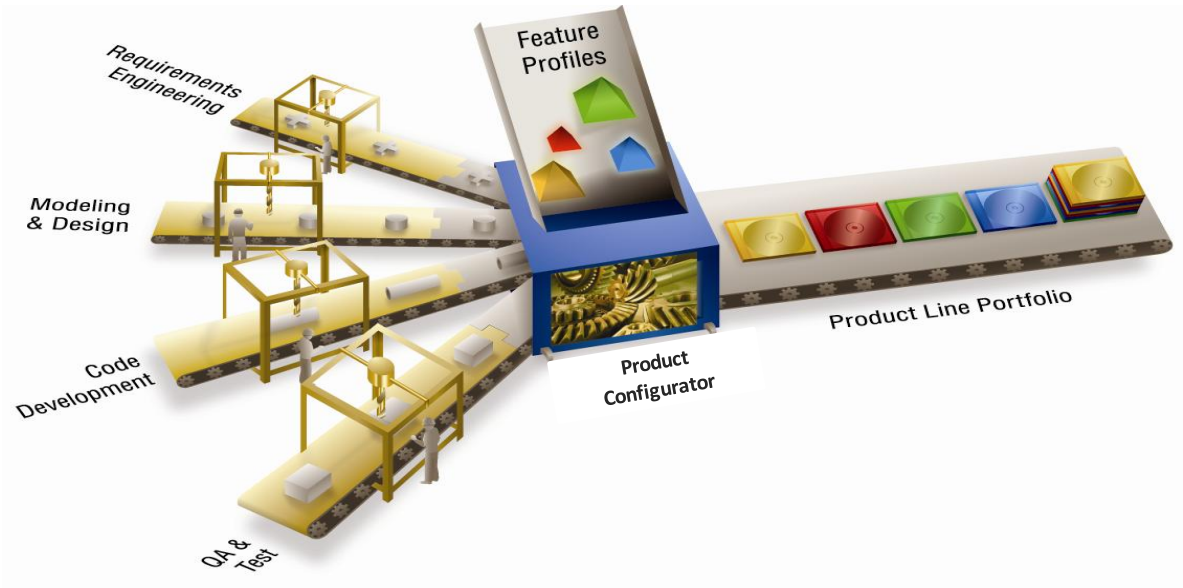


Figure 1: An efficient means of production for systems and software product-lines

In the world of hard goods, a product-line refers to the variations on a common theme, where multiple similar products are combined into one line that offers different sizes, colors, features and functions, with a common goal of filling customer need for a particular kind of item (Jensen, 2009). Economy of scale is a key aspect of the product-line concept, where greater profitability is achieved by investing in an efficient means of production that can be used to deploy different "flavors" of a product (Schmid, 2002)

As product differentiation and innovation expands from simple physical attributes to complex systems and software features – such as automotive cruise control that adapts to ambient traffic conditions, ships that can shoot down an errant satellite, wind turbines optimized for different environments and mobile phones that guide you back to where you parked your car – economy of scale and profitability become dependent on an efficient means of production for different "flavors" of products and the soft assets from which they are engineered, such as requirements, designs, source code and test cases (Schmid, 2002)

In development organizations today, virtually all systems and software engineering is performed in the context of a product-line. Nobody builds just one. Systems and software product-lines can be found in every industry across the spectrum. Throughout the first five decades of the systems and software engineering field, the methods and tools of the trade

have predominantly promoted a product-centric perspective. These 1st Generation approaches work effectively in small-scale product-lines, but have shown to be limited by a high degree of complexity as today's engineering organizations expand the scale and scope of their product-line objectives. In response, the trend today is towards a 2nd Generation approach to product-line engineering that leverages a high degree of consolidation and automation rather than a multitude of product-centric activities (Bergey, 2010)

Live Training Transformation (LT2) Consolidated Product-line Management (CPM)

PM TRADE is a leader within the Army in evolving core asset-based product-lines through the introduction and development of the Common Training Instrumentation Architecture (CTIA) and the LT2 Family of Training Systems (U.S. Army, 2009). The initial paradigm for managing the LT2 product-line introduced challenges associated with baseline divergence when components were downloaded from a centralized repository and tailored to create a unique configuration for each product or program. The primary downfall of this approach was that each new product created a new baseline, and the task of merging features and fixes from each product back into the core assets grew exponentially with each new component or product release (U.S. Army, 2011)

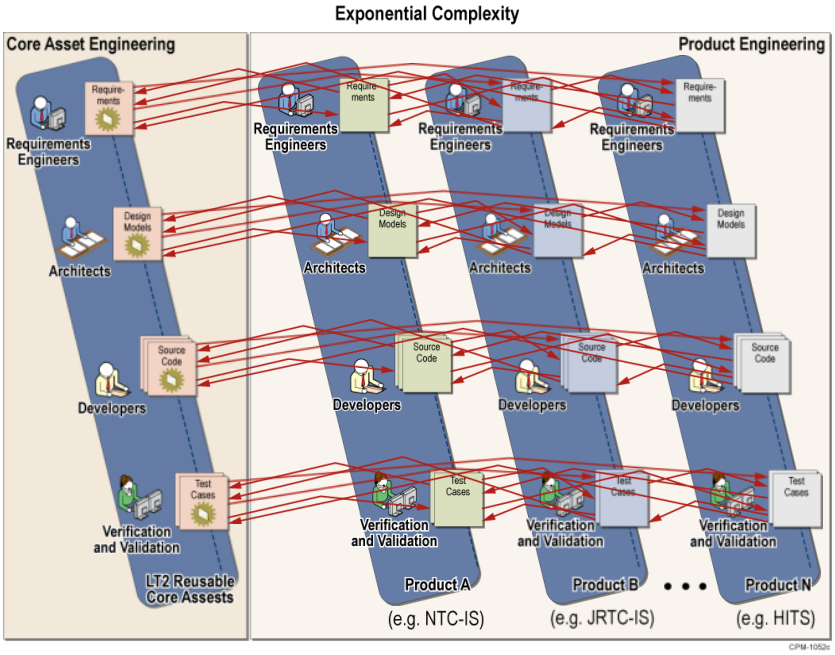
With CPM, we have introduced a new paradigm that breaks the unique product baseline mentality and creates a factory paradigm where, rather than each new product spawning a new baseline resulting in exponentially growing complexity, the CPM solution creates products from a feature driven product-line factory, generating all variants of products and programs from a consolidated set of core assets. This eliminates the uncontrolled growth in complexity management and allows us to move beyond trying to keep up with all the current product issues, and to focus on the evolution of the LT2 product-line. The CPM goal is to incrementally deploy the CPM 2G PLM approach while utilizing transparency and an open partnership between Government and industry. The activities described in the phased approach allow the CPM team to:

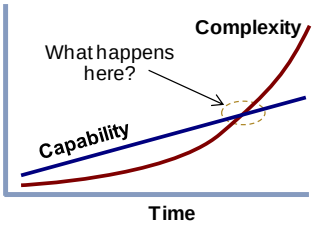
- Protect the current LT2 core assets, manage existing processes, support deployed products, and ensure there are no disruptions to ongoing LT2 Product-Line activities.
- Consolidate the LT2 Product baselines using variation management and an automated, feature-driven SPL factory, and consolidate maintenance and support activities through LT2 and War Fighter Focus (WFF) integration.
- Innovate using our 2G PLM approach; management dashboards; and architecture, product-line, and process evolution.

1ST GENERATION SOFTWARE PRODUCT-LINE MANAGEMENT CHALLENGES

The state of the industry today is a bevy of sophisticated product-centric development tools and processes that can be effectively applied to the development lifecycle of an individual product – from early inception through design, implementation, testing, deployment and maintenance. However, these product-centric tools do not independently or collectively offer an effective means to engineer and deliver a product-line. With product-centric tools, it is left as an exercise for tool users to craft the homegrown techniques for managing the "commonalities and variabilities" among products during the development of their product-line portfolios.

The repercussions of taking a product-centric perspective in a product-line setting are shown in Figure 2. The vertical blue bars highlight the product-centric focus on the development lifecycle of the individual products (A, B through N) in a product-line. The red lines illustrate the complex, tangled and labor-intensive interactions, dependencies and coordination activities required to take advantage of what is common and to manage all the variations among the similar products as the product-line portfolio evolves over time. The crux of the problem in Figure 2 is that the number of red interdependency lines grows by the square of the number of products in the product-line, explaining why complexity and effort increase exponentially faster than the growth of the product-line. Making matters even worse, the conventional product-centric traceability relationships between the different stages of the lifecycle for an individual product interact with the red product interdependency relationships, multiplying the complexity and introducing dissonance across the stages of the lifecycle.





- With 1st Generation SPL approaches, complexity quickly exceeds capability
- Exponential complexity caused by product-centric branching, clone-and-own, divergence and merging in a multi-product, multi-baseline and multi-phase environment
- With a fixed budget, the complexity fundamentally limits the number of products that can be deployed and maintained, the quality of the products fielded, and the agility for timely deployment of new products

Figure 2: Complex interdependencies resulting from the product-centric perspective

Some of the early SPL approaches added *Domain Engineering* to the development process, to better capture and express the *commonalities* and *variabilities* that exist among the products in a product-line. This made it easier to create new products in a product-line by capitalizing on the strategic reuse of the product-line *core assets*. However, these approaches relied on product-centric *Application Engineering* to complete the initial development and life-long maintenance of the products. Application Engineering resulted in the same diverging product-centric silos, with same exponentially growing interdependencies and complexity as illustrated in Figure 2, plus an additional level complexity trying to keep the core assets in sync with the product-centric assets.

The tactical development challenges of the 1st Generation product-centric SPL approaches are so large that they impede an organization's ability to achieve strategic objectives, such as hitting delivery windows, offering competitive value while controlling cost, meeting product quality demands, and expanding the scale and scope of the organization's portfolio. Comparing the ad hoc, complex and labor-intensive nature of the product-centric perspective to the sophisticated means of production found in semiconductor fabrication or in automotive manufacturing makes clear that there is an extraordinary need and opportunity for dramatic improvements in systems and software product-line engineering and delivery (Jensen, 2009)

2ND GENERATION SOFTWARE PRODUCT-LINE MANAGEMENT APPROACH

The main shift in 2G SPL is realizing it is much more effective to view systems and software product-line engineering as creating a means of production – a single system capable of automatically producing all of the products in a product-line – rather than viewing it as creating a multitude of interrelated products. The powerful, though subtle, essence of the SPL epiphany is the focus on that singular means of production rather than a focus on the multitude of products.

Figure 1 shows the single production line perspective for producing the same product-line as in Figure 2, where now the focus is on the means of production inside.

The same products, A through N (on the right side of the diagram), are automatically produced by a singular means of production composed of:

- *Feature profiles* (top) that describe optional and variable features for the products in the product-line, where each product in the product-line is uniquely defined by its own feature profile – choices for each of the optional and variable features.

- *Reusable SPL assets* (left) such as requirements, architectures, designs, models, source code components, test cases and documentation that can be configured and composed in different ways to create all instances of soft assets and products in a product-line. Variation points within these SPL assets support feature-based variation management.
- *SPL product configurator* (center) that automatically composes and configures products from the reusable SPL assets, using the feature profiles to determine which reusable software assets to use and how to configure variation points within the assets.

The challenge is the critical shift in perspective, from the vertical product-centric focus to the horizontal SPL production line focus as illustrated in Figure 3. By shifting perspective to focus on the singular means of production rather than the multitude of products, the products are relegated from the primary focus to a consequential corollary of the automated means of production. The exponential complexity of manually managing product interdependencies is eliminated and replaced by automated production, resulting in dramatic increases in the number of products that can be effectively created, deployed and maintained (Bergey, 2010; Northrop, 2009)

Three Dimensions to an SPL Solution

A key capability of the 2nd Generation PLM approach is the integration of SPL concepts into the tools, assets and processes across the systems and software development lifecycle. For the CPM Construct we have adopted a COTS 2nd Generation SPL Framework. This framework is compatible off-the-shelf with many of the industry standards in programming languages and compilers, integrated development environments, requirements management, change and configuration management, build systems, quality management, model driven development, word processors and documentation.

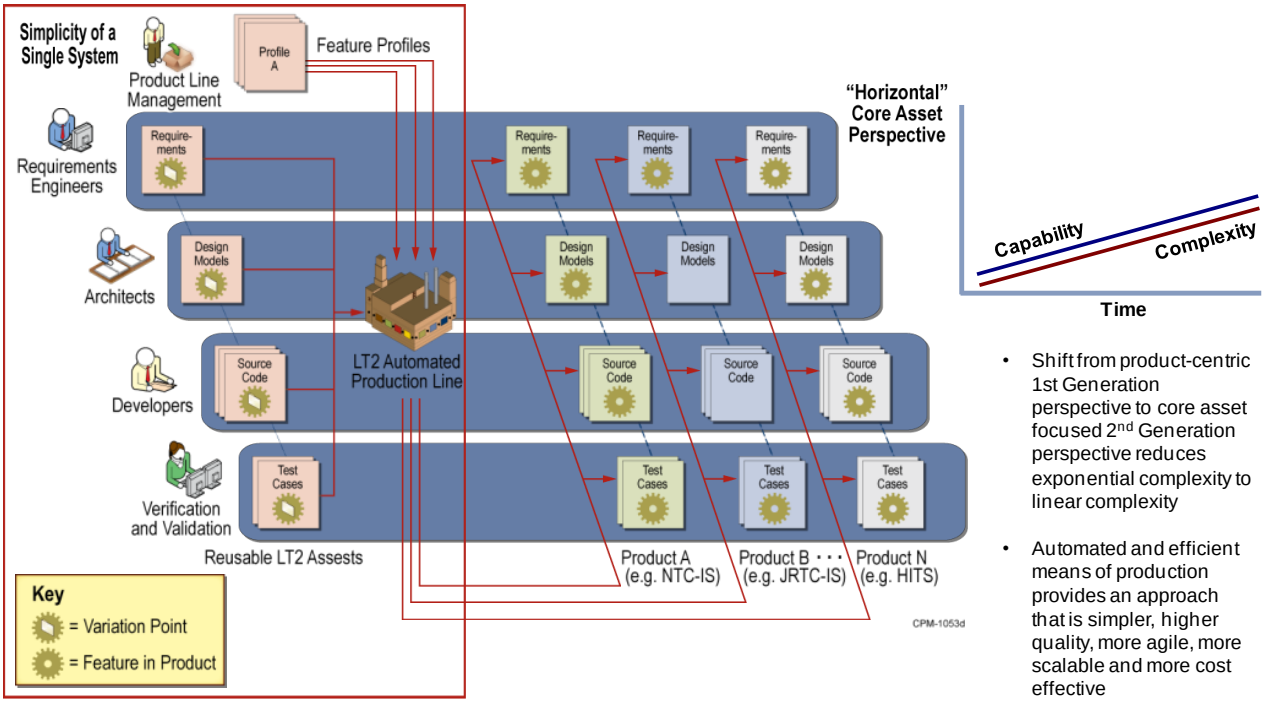


Figure 3: Efficiency of 2nd Generation SPL Approach

A 2nd Generation SPL solution is more than just a means of managing product-line commonalities and variabilities. These capabilities must be synchronously orchestrated with the other systems engineering concerns across the development lifecycle as the entire product-line evolves in time. Figure 4 illustrates the SPL concepts that expand and enhance conventional tools and processes – making them product-line aware – in three dimensions of distinct and synchronous SPL concerns.

- *Multi-product*. The feature-based variation management and automated production line necessary to engineer and deliver the multiple products in a product-line are provided directly by

the framework's feature model, variation point mechanism and product configurator.

- *Multi-phase*. The tools necessary to support the multiple phases of a product-line engineering lifecycle – from business case and analysis, to requirements, design, implementation, testing, delivery, maintenance and evolution – are the same tools already in use, augmented by the Gears SPL Lifecycle Framework to provide consistent variation management and SPL operations. Traceability mechanisms traditionally used for managing the interdependencies among the assets across multiple phases of the engineering lifecycle are also extended to become product-line aware, where traceability relationships and consistency analysis becomes aware of the implications of a variation point at either or both ends of a traceability relationship.
- *Multi-baseline*. Change management and configuration management for a product-line are done on multiple evolving baselines of the SPL assets rather than on a multitude of individual product baselines. Analogous to the supply chains for automotive manufacturing being aligned on baselines for different model years, the supply chain of soft assets for systems and software product-lines are aligned on baselines at different points in time, to synchronize complete and consistent sets of assets for the delivery of products in a product-line.

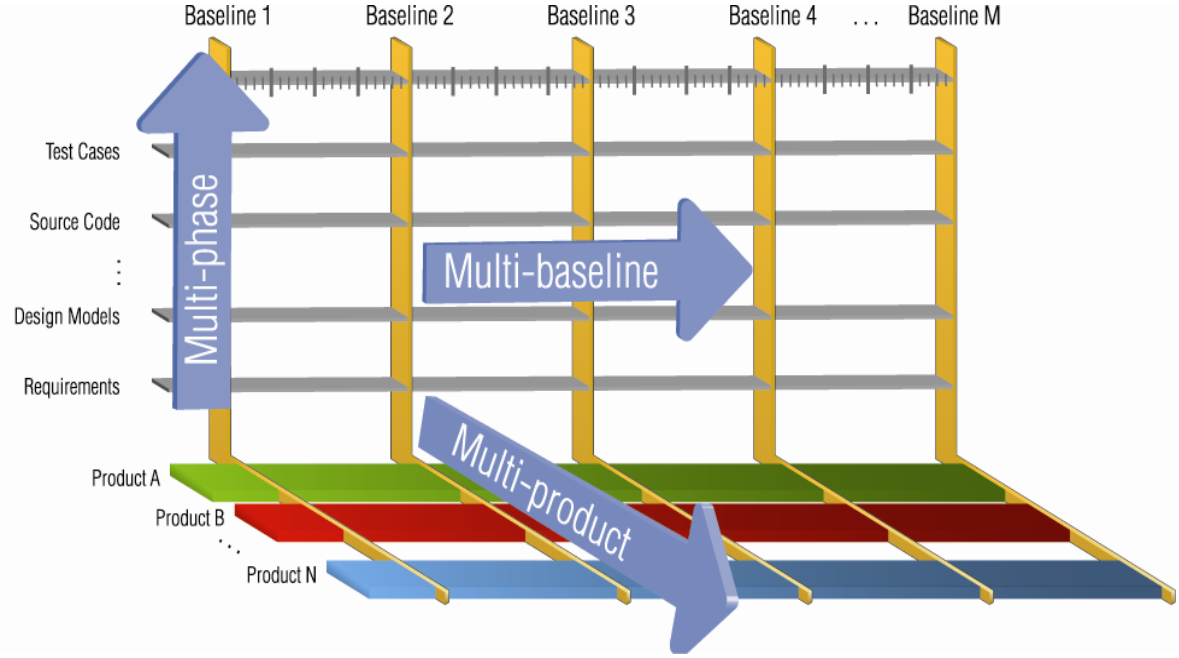


Figure 4: Synchronous concerns of an SPL solution

A 3-Tiered SPL Methodology

The final piece of the CPM 2nd Generation SPL approach, shown in figure 5, is the 3-tiered SPL Methodology (Krueger, 2007). The methodology is a pragmatic new-generation SPL methodology with a practical tiered approach that allows organizations to make a non-disruptive transition to 2G SPL practice. Each tier builds upon and is enabled by the previous tier:

- Base tier – Feature-based Variation Management and Automated Production: Tools, integrations and infrastructure for engineering product-line features, product feature profiles, product-line hierarchy, feature-based variation points in assets, and automated feature-based configuration of product-line assets into products and deliverables.
- Middle tier – Feature-based Asset Engineering: Processes and organizational structures for engineering the full lifecycle of product-line assets – from requirements to architecture, design, implementation and test – on multiple delivery streams in a production line.
- Top tier – Feature-based Portfolio Management: Business-wide management of a product-line portfolio by the features offered and the profile of features allocated to each product.

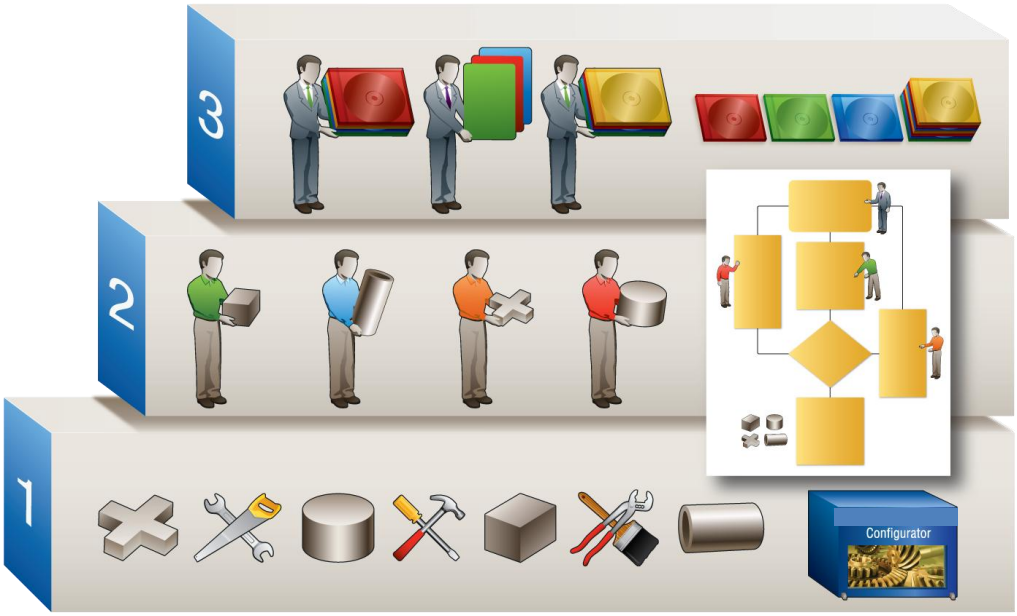


Figure 5: The 3-Tiered SPL Methodology

This methodology enables and encourages incremental transitions to SPL practice. As organizations shift from conventional product-centric software development to SPL development, three tiers of capabilities and benefits are established, sometimes in sequence and sometimes in parallel. Each tier builds upon and is enabled by the capabilities and benefits of the previous tier. That is, the capabilities at each tier provide direct benefits, but also enable increasingly more strategic capabilities and benefits in the higher tiers. The base tier provides a very tactical set of developer capabilities and benefits, which enables a middle tier of engineering management capabilities and benefits, which ultimately enables the top tier of highly strategic capabilities and benefits in the business operations.

OPEN COMMUNITY

The LT2 product-line has been developed as the Live Training common solution and is based on standards and the open model approach. It is available to the entire DoD community for leveraging and reuse. The tools and processes that help implement the 2nd Generation Software Product-Line include the LT2 Portal, WFF Portal, Dashboards, and Standards.

LT2 Portal

The LT2 Portal is the primary source for obtaining LT2 Family of Training Systems information for users, developers, and management. The LT2 Portal is a secure, web-enabled interface to the assets of the LT2 product-line and will be used for CPM in the following ways:

- **Product Deliverables** – Installers, developers and engineers may use the portal to download baselined LT2 product deliverables and updates.
- **LT2 Core Assets** – Baselined versions of LT2 product-line core assets including architectures, components, ICDs, hardware specifications, database schemas, and associated documentation will be available for download from the LT2 Portal. Developers of organizations who do not have direct access to the CPM 2G PLM production environment will be able to configure and download systems from the LT2 Portal for use in their product development. Developers with access to the CPM production environment will work directly with the CPM 2G PLM production line to configure their systems and subsystems.
- **Collaborative Development** – LT2 product-line development stakeholders may join topic-oriented members' only collaboration areas to share information—files, issues, frequently asked questions (FAQs), forums, etc.—specific to a particular product-line development area in which they are interested.
- **Help Desk** – LT2 product-line development stakeholders may obtain product and core asset support through the Help Desk on the LT2 Portal. Support options include issue tracking, FAQs, and forums.

- **CPM Working Group Requests** – The LT2 Portal contains a workflow used to manage core asset change requests. These Core Asset Change Proposals (CACPs) are located under the Collaboration menu on the portal.

War Fighter Focus (WFF) Portal

The War Fighter Focus (WFF) portal serves as the single location for WFF help desk personnel to enter and receive updates on LT2-related software issues. It also contains historical lifecycle information on equipment such as the hardware on which the LT2 software is hosted. Implementation of the CPM Construct includes an integration of the WFF portal and the LT2 Portal to share this issue and obsolescence information.

WFF help desk staff will continue to use the WFF portal as their system of record for all issues. An LT2-related issue entered into the WFF portal may be forwarded to the LT2 Portal for disposition and resolution. The integration is bi-directional so any *changes* made on either side – requests for additional information, comments, status updates, etc. – will be immediately visible to users of both portals. The expected benefits of this integration include better communication, reduced issue resolution time, enhanced LT2 product quality, and improved customer insight and satisfaction.

Dashboards

Dashboards will be used to disseminate metrics and status to the LT2 product-line stakeholders. These dashboards will contain product-line information including technical and program management data. Data presented will be decided upon through the construct design effort which will include stakeholder input. Dashboards will be presented to users via the LT2 Portal and access to data will be controlled using LT2 Portal login credentials. Access to data will be granted through administrators appointed by the CPM IPT structure. Metrics from varying efforts will be kept separately.

Standards

Establishing standards for products within the product-line is critical to allow current and future interoperability, promote reuse, and lower development and sustainment costs. LT2 product-line standards begin with the use of one of the three existing product-line architectures for live fire targetry, army training instrumentation systems, and tactical engagement simulations, respectively. Working in concert with the product-line architectures, LT2 defines further standards for specific technology areas such as: video camera and stream control, player unit communication, and player area networks.

INCREMENTAL TRANSITION

Change within an organization is hard. Even when it is painfully obvious that change is needed, it is often easier to continue doing things today the same way they were done yesterday. Second Generation SPL approaches are easier to adopt because they enable non-disruptive and incremental steps to be taken rather than a large "big bang" start-over event.

The 3-tiered SPL methodology encourages a transition to SPL practice based on the strategy of *incremental return on incremental investment* – in essence, a "start with what you've got" approach (Krueger, 2007). A product-line development organization makes a series of incremental investments, each of which yields immediate and larger returns. With a small upfront investment to transition one team, or two products, or several subsystems, the cumulative returns quickly begin to outpace the cumulative investments in terms of time, effort and money. The "profits" in time, effort and money from the first incremental investment can be used to fuel the remaining steps in the transition.
Using the incremental return on incremental investment strategy and initially focusing on the base tier of the 3-tiered SPL methodology, CPM is able to successfully introduce 2nd Generation SPL engineering practices in a selective, non-disruptive, incremental manner.

BENEFITS AND LIMITATIONS

In addition to providing the efficiencies and Cost Avoidance benefits to continue to evolve training solutions in this very resource limited environment, the CPM 2G PLM approach is offering the following benefits:

- Enables more efficient integration of the Army products by the use of common standards and products to meet training, and test requirements
- Ensures compatibility of objective system and products with evolving capabilities
- Guarantees wider interoperability before executing subsystem and device production
- Directly supports the goals of PEO STRI's Integration and Interoperability Common Components focus area to "Provide an integrated and interoperable infrastructure."

The migration from the LT2 1st Generation SPL approach to the 2nd Generation SPL approach has shared one of the challenges of 1G SPL – the difficulty of merging changes from the divergent product-centric silos back into the consolidated assets. Often times the developer that created the customizations in the cloned copies are no longer available, making the merges back into the LT2 consolidated assets difficult. However, once this consolidation is complete for CPM, the 2G PLM approach guarantees that the divergence and merging are no longer part of the engineering process.

FUTURE WORK

Throughout the life of the product-line, there will be a need to insert new technology to make improvements to the products, the architecture and core assets. To reduce the complexity of a large system as well as to allow a large system to accommodate changes or support new capabilities over time, the software architecture community has developed a Service-Oriented Architecture (SOA) paradigm.

The SOA paradigm decouples software elements and supports technology insertion through dynamically reconfigurable business logic, transport protocols and data transformations. A tremendous initial investment has already been made in the LT2 architectures, so any architecture evolution must preserve, to the greatest extent possible, that investment. One of the advantages of a SOA is that typically, through reduced complexity and decoupling of interfaces, changes can be made backwards compatible through the use of proxies, adapters and mediators.

CONCLUSION

By adopting the Second Generation Software Product-line (2G SPL) paradigm, the Consolidated Product-line Management (CPM) construct is able to avoid the divergence and merging complexity and wasted overhead. The new approach enables an automated production-line process of generating one or more products in the LT2 software product-line from a common set of core assets and feature profiles. No longer does each product team need to manually customize a new configuration baseline and assume the full maintenance responsibility for the entire cloned copy. This eliminates uncontrolled growth in complexity management and ultimately reduces sustainment and operations maintenance cost, and allows this saved time, cost and effort to be invested instead into innovations in the LT2 product-line.

With CPM 2G PLM, the Army Live training domain has made a significant investment in the systems engineering process used to achieve openness, extensibility, flexibility, and scalability of its product-line and architectures. This provides a high level of confidence in the ability to re-use the components developed and integrate them through common standards and protocols.

A primary goal is "to promote and achieve reuse." In this paper, we have explored ways to achieve this goal by way of leveraging the capabilities of the Army Live training domain. We also encourage the simulation interoperability community to continue to explore and mature technologies that focus on standardization.

ACKNOWLEDGEMENTS

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