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A Roadmap for Success: Organizational Adoption of Feature-based Product Line Engineering

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Feature-based Product Line Engineering (PLE) is an engineering discipline that allows you to efficiently manage the development of a product line, which is a family of similar systems that vary from each other in features and functions. Feature-based PLE involves commercial automation technology, but is about more than tools and methods. To achieve the most benefit, an organizational approach is needed for adoption. Successful transition requires a shift in thinking from product-centric approaches to a product line portfolio-wide sharing perspective.

This report presents a proven approach for organizational adoption of Feature-based PLE. It is based on BigLever's broad-based success in bringing organizations of all sizes and domains to the PLE vision. Elements of the approach include a three-tiered adoption strategy, spiral adoption planning, a Living Business Plan for PLE, establishing and operating a PLE Center of Excellence, and providing on-demand just-in-time knowledge and training. The report concludes with an overview of onePLE**, which is BigLever's industry-proven holistic adoption package for Feature-based PLE.**

1. Introduction

Feature-based Product Line Engineering (PLE) is an engineering discipline that allows you to efficiently manage the development of a product line, which is a family of similar systems that vary from each other in features and functions.

Whereas efficiency-enhancing approaches like Agile, Model Based Engineering, DevOps, and the like offer productivity gains in the single- or low double-digit range, Feature-based PLE been consistently shown to deliver productivity, quality, portfolio scalability, and cost improvements in the triple-digit range. As such, it is very likely the most powerful engineering paradigm in use today.

While the approach is powered by an innovative piece of technology called a configurator, and a well-defined and rigorous methodology centered around sharing engineering artifacts across the product line, Feature-based PLE is about more than tools and methods. To achieve the most benefit, an organizational approach is needed. Sharing will not happen effectively unless the appropriate organizational structures, processes, workflows, training, management incentives and remediation, and more are put in place. Organizations that wish to transition to Feature-based PLE must overcome inertia, the tendency to continue carrying out their current practices. Successful transition requires a shift in thinking from product-centric approaches to a product line portfolio-wide sharing perspective. (By *organization*, we mean the group or groups that have decided to embrace Feature-based PLE. This could be an entire corporation, or one or more divisions, departments, sections, or product line groups.)

To manage such a shift, organizations need a vision of the desired end state, and a realistic step-by-step plan for achieving it. Lacking one or the other, an organization is likely to flounder, trying ad hoc approaches or disparate approaches that create obstacles and, ultimately, lead to failure. Further, it will be extremely difficult to motivate the engineering staff to change the way they carry out their tasks, and equally difficult

to create a business case that convinces executive leadership to sponsor and support the activities necessary to bring about the needed change.

This report presents a proven approach for organizational adoption of Feature-based PLE. It is based on BigLever's broad-based success in bringing organizations of all sizes and domains to the PLE vision.

After an overview of Feature-based PLE, we provide a view into the critical components of a roadmap for successful adoption.

2. Overview of Feature-based Product Line Engineering

The following introduction to Feature-based PLE reveals why a purposeful organizational adoption is essential to gain the full benefits.

Product line engineering (PLE) is a way to create a family of systems in an efficient way by regarding the family rather than the individual systems as the entity being developed and maintained. Although examples dating back centuries can be found, in modern systems and software engineering PLE emerged from the software field in the 1980s.

Feature-based Product Line Engineering is a modern approach to PLE that emerged with the advent of industrial-strength commercial tools that automate the task of product instantiation. It is defined to be the efficient engineering of a product line using a shared set of engineering assets, a manned set of features, and an automated means of production. Feature-based PLE is underpinned by industrial-strength automation that provides consistent variation management across the entire spectrum of lifecycle engineering. It takes advantage of the commonality shared across the family, while at the same time efficiently, systematically, and consistently managing the variation among the systems.

2.1. The Feature-based Product Line Engineering Factory

The following description is taken from the recently-published INCOSE primer on Feature-based PLE (INCOSE 2019).

Organizations utilizing Feature-based PLE adopt a *factory* approach to building their products. The factory is a conceptual construct that shows how the various aspects of Feature-based PLE interact with each other. Figure 1 illustrates:

- **Shared assets** are the "soft" artifacts that support the creation, design, implementation, deployment, and operation of products. A shared asset can be any artifact representable digitally: requirements, design models, source code, test cases, BoMs, wiring diagrams, documents, and user manuals, installation guides, and more. They either compose a product or support the engineering process to create a product. They can be represented digitally and configured, and are shared across the product line.
- A shared asset used in the product line takes the form of a superset, meaning any asset content used in any product is included. There is no duplication or replication of asset content at all. This elimination of duplication is where Feature-based PLE derives its savings by eliminating work across duplicated assets.
- The shared asset supersets contain variation points, which are places in the asset that denote content that is included, omitted, or configured according to the feature selections of the product being built. A statement of the product's distinguishing characteristics — its features — is applied to "exercise" these variation points (that is, cause the content associated with each variation point to be configured to meet the needs of the product).
- A key aspect of Feature-based PLE is consistent and traceable treatment of variation across all shared asset types. Feature choices are the basis of a common lan-

guage of variation across all disciplines and at all levels of the organization. This resolves the quagmire brought about by different disciplines each using its own approach to variation.

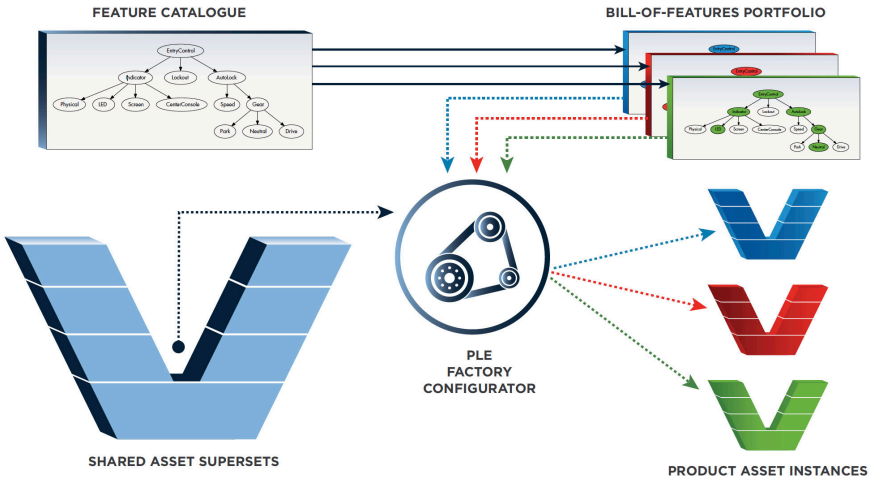

Figure 1. The Feature-based PLE Factory

- The **Feature Catalogue** captures the features that are available for each product to select. A feature is a distinguishing characteristic that describes how the members of the product line differ from each other. This provides a common language and definition of the product line's scope of variation for everyone throughout the organization.
- The features selected for each product in the product line are specified in the **Bill-of-Features** for that product.
- The **PLE Factory Configurator** is an automated software tool that applies a Bill-of-Features to all of the shared assets. It evaluates each variation point to determine if that variation point's content should be included or not.
- The PLE Factory produces as output **Product Asset Instances**, each one containing only the shared asset content suited for one of the products in the product line. Together, they constitute the artifact set for one of the products in the product line. Engineers now work on the shared asset supersets, and the Feature Catalogue, and the Bills-of-Features. Change and evolution are handled systematically through well-defined governance procedures.

Once the Feature-based PLE Factory is established, engineering assets for products are instantiated rather than manually created. A new version of a product is not derived from a previous version of the same product, but from the shared assets themselves, using the configurator. Feature-based PLE transforms the task of engineering a plethora of separate products into the much more efficient task of producing a single system: The Factory itself.

Earlier approaches to PLE almost all emphasized a strong dichotomy between domain engineering and application engineering, sometimes called core asset development and product development (Krueger and Clements 2013). Application engineering involved choosing reusable domain-engineered core assets and grooming them for use in a product as needed. Application engineering includes the obligation to choose a production strategy — that is, a way to turn the shared assets into products. By contrast, the production strategy in Feature-based PLE is fixed. It is the generation of product asset instances by the configurator – which *essentially eliminates application engineering entirely*.

Case studies for the application of Feature-based PLE include (Wozniak 2015, Chalé Góngora 2017, Clements 2015, Flores 2012, Gregg 2015, Gregg 2014, Lanman 2011). The processes that underpin Feature-based PLE are well-defined and prescriptive, eliminating much of the guesswork that typified earlier forms of PLE; it is a prescriptive and focused specialization of the general form of PLE described by the ISO/IEC 26550x family of standards. For example, process definitions and collections of best practices for Feature-based PLE are now available to practitioners (SDTimes 2019). Accompanying the maturation of Feature-based PLE are experience reports that detail how Feature-based PLE works with Agile (Gregg 2016, works with Model-Based Development (Young 2017, Flores 2017), supports high-reliability testing (Gregg 2017), works in mega-scale product lines (Flores 2012), enables automation-supported intellectual property protection (Clements 2013), works in high-security environments (Teaff 019) and more. Papers such as these attest to the maturity and critical mass of the discipline.

2.2. Gears: The automation engine that powers Feature-based Product Line Engineering

The automation at the heart of the PLE Factory is the configurator — in BigLever's case, the Gears PLE Factory Configurator, shown in Figure 2. This is the source of the savings for which Feature-based PLE is known. Practitioners make all changes, whether development or maintenance or evolution of products, inside the PLE Factory — that is, to the shared assets supersets, the Feature Catalog, or the Bills-of-Features. Gears then automatically applies that work to every product that needs it. If, for example, a change to the product line affects on average four members of the product line, then the engineering team does the work once and Gears applies it to the four products that need it. This is a net savings of three units of work, meaning that your engineering team is now four times as effective — as *productive* — as they were before Feature-based PLE. This whole-integer factor of improvement is typical with Feature-based PLE.

Gears makes possible many of the hallmark characteristics of Feature-based PLE, such as:

- A uniform language of variation — features — that define the product line's scope.
- A uniform variation point mechanism, based on feature selections, that is available directly within existing tools and their associated assets, to manage feature-based variations across all stages of the engineering lifecycle.
- The ability to model a product line structured as a system of systems as a product line of product lines.

To a product line practitioner, Gears provides

- The development environment to:
  - create, organize, and maintain your production line
  - build and maintain the feature catalog and feature profiles for your production line
  - attach shared assets to the production line, edit the shared assets to define variation points and create the instructions to Gears for how to exercise them
  - configure the shared assets to produce product-specific instances based on a feature profile.
- Tools to aid in production line analysis and comprehension:
  - semantic checker for all elements of a production line
  - query search tool over a production line
  - membership analysis tool to determine in which products a given file, directory, or variation point is used

- statistics report on the production line, including coverage statistics for production line scope, ratios of common versus variants artifacts, and so forth.

- A command line interface for integration into automated build systems and other tools in your development and production environment.

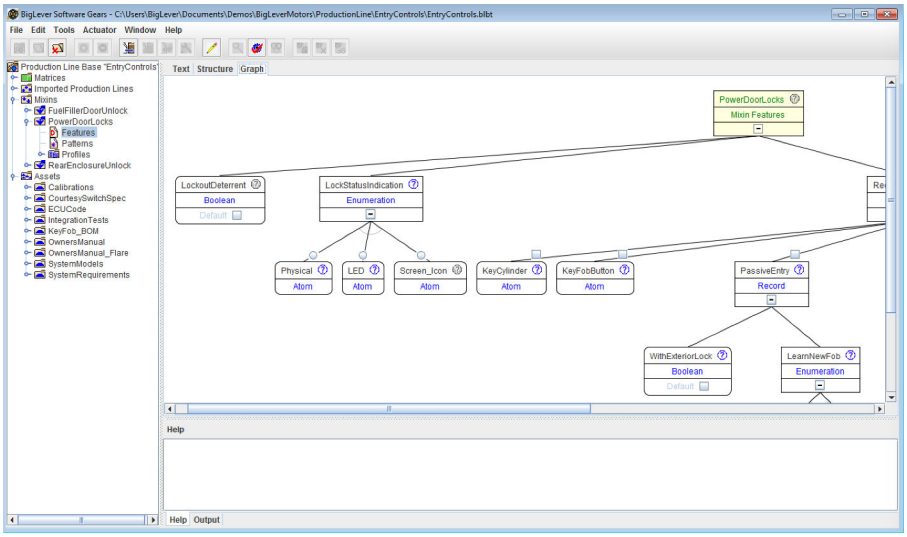

Figure 2: Gears development environment user interface. The parts of a production line — that is, a Feature-based PLE factory — are shown in the browser pane (left). The display pane (main) shows the part of the production line selected in the browser pane (shown here is an excerpt of a feature model). The output pane (bottom) is where query results and Gears messages are shown.

3. Foundational ingredients for successful adoption of Feature-based PLE

The adoption techniques described in this section, all BigLever innovations, have powered some of the most successful PLE adoptions in industry, resulting in some cases in documented and published cost avoidance of hundreds of millions of dollars.

3.1. Apply a three-tiered adoption strategy

We find that three parts of an organization must be engaged to ensure a successful adoption. An adoption strategy that neglects one or more of them is likely to fail. These so-called organizational tiers are staffed by people who have different skill sets, motivations, organizational responsibilities, and therefore different perspectives when it comes to adopting a new methodology. Recognizing and address these three tiers is the first ingredient of a successful adoption strategy. Figure 3 illustrates the three tiers.

The base Technology tier puts in place and maintains the tool and technology environment to operate the PLE Factory. This tier is about installing tools: Gears, engineering tools with which Gears integrates, CM tools, workflow tools, and whatever other tools are part of the organization's tool ecosystem needed to take products through their entire lifecycle. The tools must work together and perform well in the organization's IT and network environments, and users must have access to them. Think of this as the fully functional factory (in the conventional manufacturing sense) but without any of the people inside to run the machines.

The middle Technical Organization Management tier focuses on the people, roles, and processes that operate the PLE factory. In combination with the Technology layer, this layer provides a fully operational Feature-based PLE Factory capable of produc-

ing the Product Asset Instances (see Figure 1) for all of the products in a product line portfolio. To continue the analogy, this tier is about the people who walk into the Technology tier's factory, trained and ready to operate the machines.

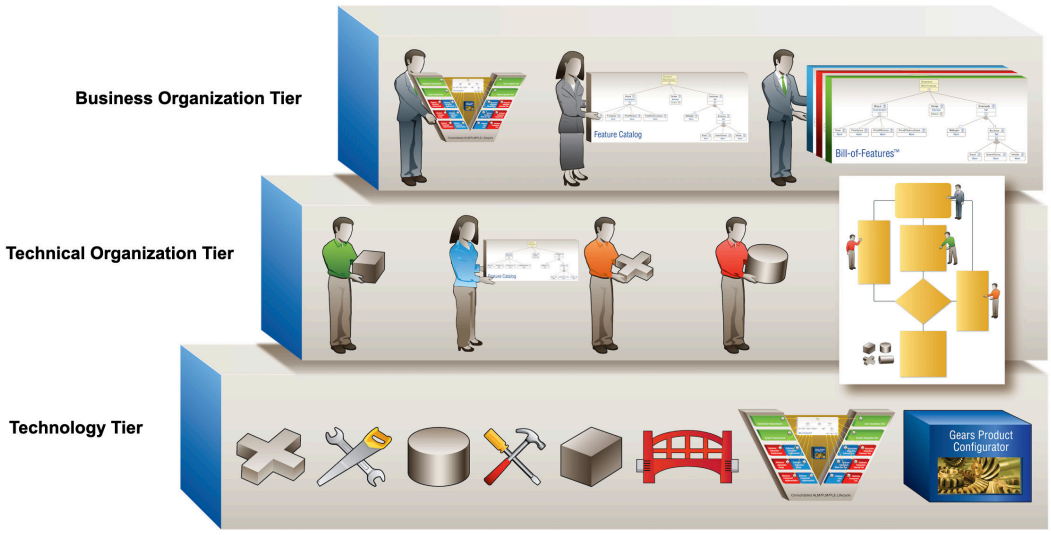

Figure 3: Three tiers of a Feature-based PLE organization

The top Business Organization Management tier focuses on the people, roles, and processes that utilize and leverage the Feature-based PLE Factory to achieve the business objectives of the enterprise. But it also focuses on the required processes for enterprise leadership to establish the PLE Factory, oversee the adoption, remove obstacles to organizational change, and to provide the necessary support for the PLE Factory during its operation. Using the analogy to a conventional factory, the Business Organization tier provides guidance and support for executive leadership. Think of this group as working in the office high-rise that overlooks the factory.

The purpose of all tiers is to establish, operate, and maintain a PLE Factory (implemented as a Gears production line) that will be used to build and deliver all the products in the product line.

The obvious tendency with a transition to Feature-based PLE practice is to think bottom up. That is, begin with the Technology tier, and then start on the middle Technical Organization Management tier, in sequence, after the technology is fully established.

While this style of transition is simple and effective, we have found that it is also effective to address the tiers incrementally and in parallel. Imagine the incremental transition effort growing from left-to-right rather than bottom up. Initially enough progress is made in all three tiers to allow the PLE Factory to launch with a reduced but useful capability. Over time, more and more is put in place in each tier, allowing the PLE Factory to accomplish more.

For example, an organization may decide to first focus its Feature-based PLE Factory on the requirements and source code for the product line, but defer other types of shared assets until later. That decision implies a set of adoption steps in all three tiers. The Technology tier would include Gears plus those tools dealing with requirements and source code. The Technical Organization Management tier would address the processes and training necessary to have the PLE Factory operate on those shared assets.

This scenario illustrates the need for the second ingredient of successful adoption: A Spiral Adoption Plan.

3.2. Apply spiral adoption planning

You wouldn't let any other project of organizational importance drift aimlessly without a carefully considered project plan, and PLE adoption is no different.

A Spiral Adoption Plan is similar to a project plan where, in this case, the "project" is the successful adoption of Feature-based PLE by an organization. It lays out milestones and assigns responsibilities for those milestones. BigLever's Spiral Adoption methodology is illustrated in Figure 4.

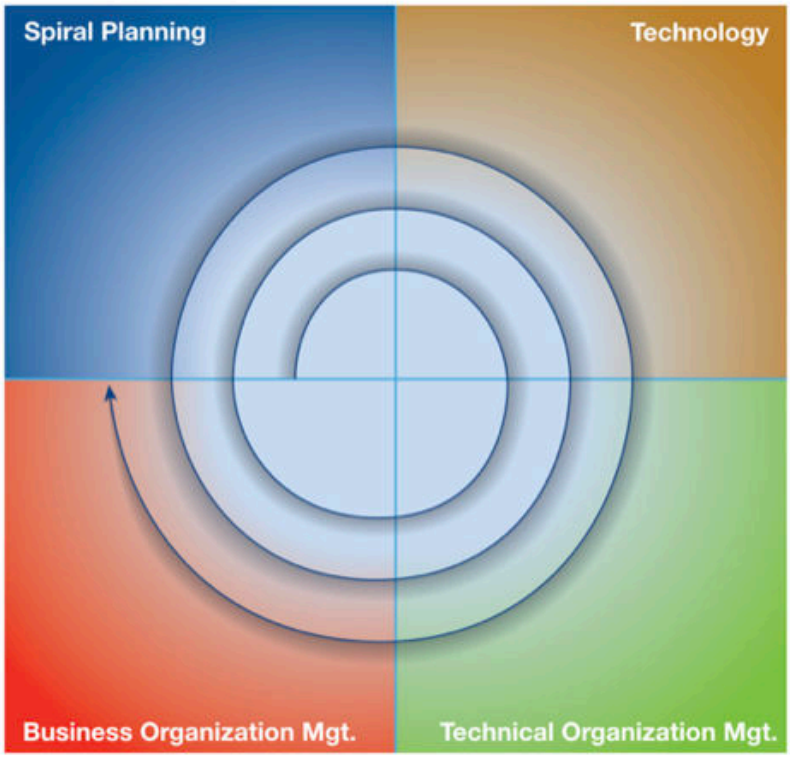

Figure 4: Spiral Adoption Model for Feature-based PLE

Organizations can take the journey to Feature-based PLE in small steps that they can absorb. Nevertheless, each step brings benefit and leaves the organization better off than it was before, and closer to the goal of full adoption. To facilitate incremental transition, we have a spiral model of adoption. Like all spiral models, it charts an incremental path through various areas of activity. With the completion of each cycle, the organization is further along its adoption journey (as measured by the distance from the origin point at the center). Progress is steady, but no cycle overwhelms the organization's ability to absorb new practices and processes.The four quadrants are:

- **Spiral Planning,** where the overall journey around the spirals is planned, plotted, and monitored. Planning starts with the definition of the deadline to "go live" for the PLE Factory, and the cadence and number of users to bring into the factory with each spiral. Subsequent spirals through this quadrant will revisit the plan, fine-tune it, include new organizational units under its scope, and monitor and course-correct the roll-out.
- Three quadrants corresponding to the three tiers described in the previous section. In each quadrant, activities required of the respective tier are incorporated into the plan. Specifically:

- **Technology,** which comprises activities concerned with establishing the technological basis for the product line, setting up tool environments, building feature models, and modeling the initial product portfolio. Its concern is with the infrastructure of the PLE Factory.
- **Technical Organization Management,** which focuses on organizational and process adjustment to move the organization from project silos to a true PLE factory. Think of activities here as focusing on staffing the operating the factory.
- **Business Organization Management,** which captures on the organization's driving goals for adopting PLE, along with their importance and urgency, and involves overseeing and directing the PLE Factory. These goals, and the organizational and market context that drive them, inform the adoption plan to ensure that the goals are being addressed.

The quadrant activities in any one spiral may be prosecuted in any order, and a particular spiral need not include activities from every quadrant.

Inserted strategically within each spiral should be explicit "short-term wins," which are events where PLE brings about an improvement or where the adoption meets a planned milestone. These "wins" should be celebrated and communicated throughout the organization as part of a comprehensive plan for communication about PLE, which brings us to our next ingredient: A Living Business Plan for PLE.

3.3. Be guided by a Living Business Plan for Feature-based PLE

A successful enterprise-wide transition to PLE requires a clearly articulated business plan that includes the goals of the adoption, and in particular the cost of *not* undertaking the adoption. What are the threats to the business that make the current status quo unsustainable? In short, why PLE? And what is the urgency — perhaps the most important among all the necessary ingredients for organizational change — involved in moving to PLE?

The business plan also includes required investments, expected returns, and a declaration of the groups who will be involved across the organization and the products or product families that will come under the PLE umbrella. Overall, it describes and quantifies the business value underlying the decision to adopt PLE.

The business plan is created, maintained, and owned by the executive leadership sponsoring the PLE adoption. It comprises seven sections:

- **PLE Scope:** Which organizational units — business units, product areas, or specific product lines and/or products — will eventually be brought under the PLE umbrella? What subsystems and assets should be managed with PLE, both in the short term and long term?
- **The Guiding Coalition:** A key ingredient of organizational change is identifying and empowering the *Guiding Coalition.* The Guiding Coalition comprises respected business, management, and technical leaders with enough power to guide the organizational transition to PLE. This group should work together as a team to guide the transition and remove any roadblocks that are threatening to impede progress. Their job is establish the vision, urgency and importance, communication, funding, process templates, engineering platform, assessment, and sustainment of PLE.
- **Importance and Urgency:** An organization with no compelling reason to change won't change; inertial forces will always defeat good intentions. This section of the Living Business Plan establishes the motivation behind the transition, and why it's critical to make the transition. Beyond importance, however, is

urgency. Creating and instilling a sense of urgency throughout the organization is the most critical enabler of organizational change.[1]

- **Vision for PLE Strategy:** What is your organizational vision for adopting PLE? What will your organization look like when PLE is your normal way of doing business? What will its competitive position be? This section captures that vision, its core messaging, and any compelling visualizations available to motivate and inspire individuals and enact the change to PLE.
- **Communication Strategy and Plan:** This section answers the question: How will the vision and the progress in achieving it be communicated throughout the organization? Having a vision for PLE is essential but what you do with your vision after you create it will determine your success.
- **Funding Plan:** How will funding to stand up, operate, and sustain the PLE factory be provided and managed? For example, if the organization is funded by different customers' purchase and ongoing maintenance of different products, how will those separate funding streams be parlayed equitably into an overall funding source for the PLE factory?
- **Mitigations for Roadblocks and Risks:** Like all complex undertakings, risks and roadblocks need to be identified and mitigated for the transition to PLE. In this session the group will identify and capture risks, the potential impact of each, and mitigation strategies to put in place to avoid or ameliorate the impact. Get started with a purposeful launch

The first steps of adoption are a pair of intense hands-on working events, facilitated by BigLever PLE experts, typically two to three days in duration:

- **The Technical Getting Started Workshop** entails the interactive creation of a pilot project that illustrates product line concepts in your application domain and organizational context. This provides input to executives and organizational managers as to the feasibility of the technological approach, and enables your technical leadership to weigh in on the advantages and issues associated with the PLE factory approach in your organization's own context.

  The primary outcome will be one or more production lines that satisfy your product line needs, with feature models that correspond to your products and shared assets configured to support them. Another important outcome is the knowledge and hands-on experience you will gain with advanced product line strategies and techniques, as well as specific knowledge applicable to your situation and context.
- **The Business Getting Started Workshop** is the business-oriented analog to the Technical Getting Started Workshop. It gathers your organization's business leaders and product and project managers to produce the first iterations of the Living Business Plan and the Spiral Adoption Plan.

Besides producing their respective results, these workshops constitute a formal launch of the adoption effort, which itself communicates the commitment and importance placed on PLE by the organization's leadership.

3.4. Establish and Operate a PLE Center of Excellence

Organizations applying PLE in multiple parts of the enterprise (for example, across business units or on multiple product lines) gain important benefits from centralizing the production and maintenance of their body of PLE material and knowledge.

[1] "By far the biggest mistake people make when trying to change organizations is to plunge ahead without establishing a high enough sense of urgency in fellow managers and employees. This error is fatal because transformations always fail to achieve their objectives when complacency levels are high." — John Kotter, *Leading Change*, Harvard Business Review Press, 2012

Applying the most fundamental of PLE's tenets, sharing these materials — and equally importantly, the knowledge and experience they embody — is key to accelerating the PLE transition across the three tiers (as discussed in section 3).

Re-inventing these foundational elements within each part of the organization can result in the loss of vital insights and knowledge. And, it can greatly impede the organization's PLE transition momentum by creating repetitive, low-value work and duplication — the antithesis of PLE.

Serving as the focal point of this sharing is the role of a *Product Line Engineering Center of Excellence (COE)*. A PLE Center of Excellence assists the overall organization, and supports individual PLE efforts, by imparting consistent and high-quality material, assisting and helping to carry out activities with skill based on experience — while drastically reducing the amount of re-discovery, false starts, re-work, and duplication that would otherwise occur across the various PLE projects.

3.5. Provide a PLE Body of Knowledge for on-demand, just-in-time knowledge and training

BigLever's unmatched experience in PLE has allowed us to create an industry first: A comprehensive body of PLE knowledge structured and available on-line for use throughout your organization.

The Body of Knowledge contains detailed process descriptions for every aspect of Feature-based PLE, including all of the activities involved in establishing and operating your PLE Factory:

- producing your Living Business Plan and Spiral Adoption Plan,
- establishing and managing the PLE Factory,
- establishing the right organizational structure for the PLE Factory,
- building a Feature Catalog and Bills-of-Features for your product line,
- engineering shared asset supersets with variation points and traceability,
- using the PLE Factory to build and deliver products, managing change and product line temporal evolution,
- ensuring IP protection and operating the PLE Factory in a classified environment,
- funding policies for the PLE Factory,
- defining PLE metrics and measures, and much more.

Anyone in your organization can go to the Body of Knowledge, look up their role, determine its definition and the processes and activities for which they are responsible, and then undertake associated training.

The training materials offered by the Body of Knowledge include an inventory of specialized courses, best practices compendia, Quick Reference Guides, slide presentations, detailed how-to videos, white papers, and more.

4. Holistic Adoption: onePLE

BigLever's experience in bringing PLE success to product engineering organizations is unmatched in the industry. Our customers include the largest companies in automotive, aerospace, defense, aviation, e-commerce, and other industry sectors. This experience has enabled us to create a robust, repeatable path to success called **one**PLE™.

The name **one**PLE comes from the idea that we provide a single deliverable to your organization: A successful product line engineering capability. BigLever provides the organizational change expertise, services, body of knowledge, training and mentoring, and technology necessary to achieve that success — all in a single package.

It is available for organizations of any scale: an entire company, a division, a business unit, or the organization responsible for the production of a single product line. For one fixed price, **one**PLE includes:

- A license for Gears and its integration bridges for each member of the organization who needs it
- The Getting Started Workshops described in Section 3.4, facilitated by BigLever experts, to establish your PLE Factory and launch your PLE journey
- A jointly developed Spiral Adoption Plan and Living Business Plan that together address all three tiers of your PLE organization
- Full access to BigLever's Body of Knowledge for Feature-based Product Line Engineering
- Guidance to set up a PLE Center of Excellence in your organization.

The result is the shortest-path solution to PLE self-sufficiency and success.

For more information about **one**PLE or to get started, contact: sales@biglever.com.

5. Conclusions

The *technological* basis of Feature-based PLE, such as the Gears PLE Lifecycle Framework, has come about based on years of experience in observing, capturing, and addressing the needs of product line organizations. Based on many years of experience in helping organizations successfully adopt the product line engineering approach, we now follow suit with a proven *organizational* basis for Feature-based PLE as well. The approaches in this report are useful not only for the operation of PLE practice, but also in understanding, explaining and justifying the PLE approach, as well as for planning and making transitions into PLE practice.

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