Podcast summary

Managing quality in Product Line Engineering

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This document accompanies a podcast discussion led by MWD Advisors on "Managing quality in Product Line Engineering (PLE): an automotive story". It summarises the main guidelines and key messages highlighted in the discussion. To access the podcast audio please follow this link or see the instructions on page four of this document.

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Introduction and overview

Delivering software and hardware (mechanical, electrical and electronic) systems in line with an overall product delivery schedule presents many challenges, most notably when maintaining and managing effective quality and testing control against stated requirements. Product Line Engineering – or PLE as it is often referred to – is both a mechanism and an approach that is seeing growing support and mainstream adoption for managing the feature variation and evolution of systems, products and software applications. It has had noteworthy success in improving and managing reuse and quality within many different product markets.

PLE is not just about software feature variation management. It provides a platform framework for governing the development and delivery lifecycle of all the variations of a product portfolio and the combination of system components (mechanical, electrical and electronic hardware, software) that go to make up each product variant. PLE ultimately provides the mechanism for the parallel development, delivery and management of reusable systems across the domain of disciplines involved in delivering a complex portfolio of interconnected products and components.

IBM sees PLE as a vital qualification for "Smarter Product" enablement and defines it as:

a lifecycle approach that applies best practices and tools to allow companies to deliver more complex portfolios of products in less time and for less cost. This life cycle approach encompasses all the development and delivery domains across the product delivery process.

There are many aspects to a PLE strategy and platform that need to be brought into sharp focus for end user organisations in key industries such as automotive, in order that they may recognise and understand both the business benefits and long term governance and quality management that can be achieved.

In this podcast we discussed the challenges in managing quality in Product Line Engineering. The discussion focused on five key points:

1. The business impact when quality management and testing for the software and product delivery process is not kept in line.
2. How a Product Line Engineering strategy can bring alignment between the software and product delivery process and ensure effective and progressive quality outcomes.
3. The key tools, processes and methodologies that need to be in place to help support effective implementation of a quality, focused PLE strategy.
4. Getting the business to invest in a process for managing software variations that is aligned to the product delivery process and identifying the metrics for success.
5. The future of PLE-driven software development services within the automotive industry, especially in driving innovation and business value.

Key conclusions and recommendations

The discussion delivered a number of conclusions and recommendations about managing quality in a PLE strategy and framework based on the experiences and knowledge of the participants in working with PLE frameworks within the automotive industry.

- **A lifecycle approach for maximum value and quality.** PLE requires a lifecycle approach and a long term strategy to achieve the maximum quality and value benefits. This requires organisations to assess carefully what they hope to achieve – e.g. efficiency, reducing complexity, product innovation etc. – and to closely examine their existing practices and tooling to ensure a pragmatic strategy for implementation. The metrics for success and the pain points that will be addressed are critical to engaging business or internal management sponsorship.

- **A process focus is as important as the right tools and technology.** If organisations address either in isolation, they run the risk of introducing further complexities or implementing the wrong tools. The process and tool strategy is an evolving process that should evolve with the maturity of a specific product line. Just as important is an understanding of the relationships and cultural attitudes that exist between the various domains and teams within your organisation in order to be able to understand the changes that need to be made and the tool support required.

- **PLE is transformational but can be implemented through a modular strategy.** For the most effective engagement of all relevant stakeholders across the organisation, incremental transitions that require incremental investments and produce incremental returns which allow you to mature the product line at a manageable rate have proven to be the most successful. Automotive organisations like General Motors have implemented a PLE strategy for 15 years with both qualitative and quantitative success results. However, they started off with a small product line development that has progressed in line with their maturity allowing them to grow it to incorporate more complex system and software variations.

- **Transformational processes like PLE can be an intimidating proposal for organisations to take on board.** Be aware of this, but know that there is extensive educational literature backed up by wide ranging success stories and case studies. This is supported by an increasing number of dedicated conferences which bring together long-term practitioners from across the spectrum of industry verticals, vendors and a multitude of interested parties to share experiences, identify common challenges and solutions.

- **PLE requires a cultural mindset shift with a focus on reusable assets.** A big change comes when there is a mindset shift from thinking about a product line as managing all common components to one where the components are viewed as reusable assets within the product line. With the maturity of their product line GM now views application-specific contents such as Environmental Control Units (ECU) as reusable content with a single application.

- **PLE is a software systems and hardware lifecycle process.** You cannot approach PLE as a single tool or a single development activity since it has an impact from the very beginning of the product lifecycle, i.e. from requirements and design through to delivery, maintenance and end of life. PLE spans the lifecycle process to encompass all the development and delivery domains across the product delivery process, from requirements through to testing and finally integration of all the constituent parts. Therefore, you need to think of the different product components or systems (i.e. any combination of software, mechanical, electrical and electronic parts) as a reusable asset which means that there will be a level of hardware standardisation – or at the very least, standard hardware capabilities – to provide some element of standard interfacing. At GM, this further cemented the need for the software engineering team to think in terms of systems and expand their product line thinking to include the hardware surrounding the software as well as the software element itself.

About the podcast

The discussion was led by Bola Rotibi, Principal Analyst at MWD Advisors.

The three guest speakers joining the podcast discussion were:

- Len Wozniak, Manager of Software Process and Powertrain Controls Architecture for General Motors and the software engineering process lead on GM's process leadership board that manages the Electrical and Controls Engineering Process covering approximately 2,500 engineers in 13 countries.
- Dr Charles Krueger, the founder and CEO of BigLever Software, the leading provider of systems and software product line (SPL) and Product Line Engineering frameworks, tools and services, with proven expertise in leading commercial software product line development teams, and helping companies establish some of the industry's most highly acclaimed SPL practices.
- Michael Rowe, a technology strategist for IBM's Rational software brand, owning IBM's Product Line Engineering solution offering and working across Rational and with business partners to address customers' Product Line Engineering needs.

We thank all our guest speakers for their valuable insights and contributions to the discussion.

Listen to the podcast discussion

To listen to the podcast discussion in full please follow this link or copy the link below into your web browser:

https://www.ibm.com/services/forms/signup.do?source=swg-rtl_tl_genisv&S_PKG=pd_BigLever-PLE-automotive

Podcast summary

In this section we drill down into some of the detail under each of the five discussion points introduced in *Introduction and overview* above.

Discussion point #1: The business impact when quality management and testing for the software and product delivery process is not kept in line

When there is disconnect between the testing and quality management processes for all the development and delivery domains across the product delivery process, the impact on the business can be quite significant and potentially even catastrophic if it leads to failures that impinge on safety. The discussion identified a number of impacts to the business when quality management and testing for the software and product delivery process becomes decoupled.

Delivery of "failure time-bombs" in products out in the field

Decoupling the quality management processes of all the development and delivery domains across the product delivery process can lead to the deployment of products that have been falsely tested and therefore potentially flawed in terms of quality. In this situation, any testing and quality process done in isolation rather than collectively from a product line perspective is in danger of not taking into account the product as a whole, and is therefore likely to miss any environmental or other impacting factors and constraints (such as regulation compliance, safety critical constraints etc.) placed on the product once it is deployed out in the field. Not thinking of the product delivery process as a unified product line for all development and delivery domains allows for disconnects between requirements and testing processes that have cross-cutting concerns according to product feature variations and goal and usage intentions.

All of this can and will lead to quality holes that can drain and adversely impact the business's bottom line from a financial, integrity and time-to-market perspective. Recent headlines show a real world example of the effect that a product recall had for a leading global player in the automotive industry when it suffered a quality failure in one of its car models that was later resolved by a simple software modification. The resulting slur on the company's brand integrity along with the financial costs associated with the product recall, problem resolution, legal claims, and the PR to deal with the aftermath of the quality breach and to reassure existing and future customers succinctly demonstrate the impact in business terms when the quality management process fails at any point.

Disconnected and disjointed application and mindset making it ripe for quality holes that drive up costs

Thinking of the software and product delivery process as a unified product line for delivering and managing product feature variations that can be brought about through software systems requires a shift in mindset and attitude. Failure to bring about this necessary change affects all processes, allowing disconnected and disjointed applications of key management processes such as quality. Not having a unified view and approach to the quality management process makes it harder to realise cost efficiencies that can be made in the quality and testing processes. Within the automotive industry, developing vehicles can be a complex process involving interconnecting "systems of systems" delivered through multiple product lines. The testing requirements and testing process can quickly become overwhelming especially when integrating the components and systems. Taking a product line approach to the whole process allows engineers to focus on the testing that needs to be carried out as well as providing an opportunity for more 'eyes' looking at the testing requirements across the entire product line as opposed to just one aspect of it. The overriding gain is an ability to really focus on where changes occur and where integrations take place, allowing teams to streamline and target the testing process appropriately. Ultimately businesses cannot afford to not have a quality management process that spans and interconnects an entire product line and that addresses all feature variations.

Whilst a bug in one component may be propagated to all related product variants, the product line framework and the visibility it affords allows faster detection of impacted products and the ability to focus resources on the issues to minimise the impact out in the field.

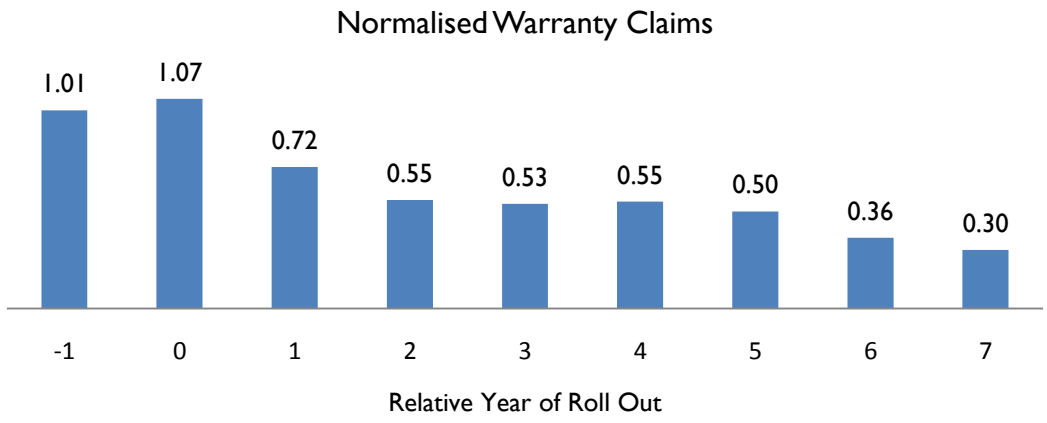
An inability to contain quality defects and lack of visibility into the true cost and business impact when a change is made

When engineering teams fail to see or think of the quality management process for delivering an individual component as part of a wider connected quality management framework, they fail to recognise the value of what a product line approach to all the interconnecting systems (software, hardware, electrical and electronic) can deliver towards identifying and containing defects across multiple variants of the product. Having the visibility into all connected components and systems, as one would have within a product line framework, can alleviate the fears that engineers have in understanding the full impact to the entire product line when a fix is made to one of the components. A disciplined and traceable approach to the entire product line allows the business to make better and more sustainable plans for raising the overall quality across the entire product line. Therefore fixing a bug or making an enhancement allows engineers to assess the potential products in a product line that will be impacted as well as enabling the business to maintain or improve quality levels as they scale and scope their product lines. Achieving this through individual product lines may not deliver the full quality benefits and would take longer to implement.

General Motors, who have been implementing a product line engineering framework approach for the last 15 years, found that as a result there are less unique components that they have to understand and diagnose. In addition, the number of bugs that have slipped through their testing process has reduced more than the impact from such bugs has increased. Their speed in detecting issues and their ability to resolve them fast has greatly increased, thereby minimising their impact once the product has been deployed out in the field. This is due for the most part to the prevalence of reuse that a product line drives.

The company has been able to demonstrate quantitatively the relative trends for the reduction in warranty claims (i.e. released product quality) made over a roll out period spanning five consecutive years of their PLE implementation. The graph in Figure 1 below shows data that is normalised to the average of the five years prior to roll out which presented a flat trend.

Figure 1: Normalised and generalised warranty claims for the 5 years roll out period after implementing a PLE approach



This chart demonstrates the reduction in warranty as an indicator of improvements in the quality of released products through product line delivery. Source: General Motors

Ultimately, through PLE, quality will improve but it should be seen as an aggregate of all the quality improvements over the maturity of the product line and as more product variations are incorporated into the product line.

One of the earliest impacts of PLE to General Motors' software was having more people looking at the software. With this level of exposure to the software came the opportunity for more applications for the software, allowing them to survive the early immaturity in the alignment between their quality processes and the product line. Improved alignment has enabled them to gain greater efficiencies in their testing processes for much less cost. As a result, the efficiency gains have allowed the company to invest in more extensive testing opportunities that can further raise quality.

Reuse in the automotive industry and other manufacturing industry verticals is very common, especially when one considers the families of products that are often built. Therefore it is critical that the quality management process is consistent and aligned for all the development and delivery domains across the product line.

Discussion point #2: How a Product Line Engineering strategy can bring alignment between the software and product delivery process and ensure effective and progressive quality outcomes

The discussion highlighted the positive benefits that a PLE-focused strategy and framework had on improving quality.

PLE drives a modular and asynchronous development approach to software activities that is more in line with a factory or production line assembly – a core pattern for Product Lifecycle Management (PLM)

A significant challenge in running a large scale product line made up of many different products (e.g. a car), is that each of the products are developed along different timescales and are needed for assembly at different times and often by disparate engineering teams and domains which may or may not communicate or collaborate. PLE ultimately provides the mechanism for the parallel development and delivery of reusable systems across the domain of disciplines involved in delivering a complex portfolio of interconnected products and components. This perspective on managing domain and discipline convergence is covered in more depth in a complementary podcast, *Underwriting the convergence between application lifecycle management and product lifecycle*[1].

The timescale differences involved in coordinating product components impact both the front and the backend of the product delivery process. Addressing the disparate time differences requires you to put a substantial amount of effort and focus into decoupling the methods and processes by which you use to deliver the individual product pieces so that they are more in-line with and attuned to product line assembly. This decoupling process is a core feature of PLE that serves to tie together all the different aspects of a product – software, hardware and electrical/electronic. The benefits of decoupling for an organisation like General Motors is that it allowed between a third to half of their business to run asynchronously; at the same time the activities were aligned to the overall assembly / integration process and timeline of the complete product. In short, it allowed them to separate and carryout independently the writing, creation and implementation of the software from its deployment into different products.

There is no "one size fits all" rule to defining the decoupling process other than a requirement for any company attempting a PLE strategy to spend significant time thinking about the methods and processes that they would look to decouple. The decoupling process can specifically have a positive impact on key processes of the software lifecycle.

[1] https://www.ibm.com/services/forms/signup.do?source=swg-rtl_tl_genisv&S_PKG=pd_BigLever-PLE-ALM-PLM

PLE delivers a testing strategy and focus that is more attuned to the asynchronous nature of production line delivery

As a result of the effort and energy GM put into defining their decoupling methods, the company now runs a very factory-like set of software activities that is more in keeping with the production line framework of product delivery. This ultimately has a positive impact on quality and time-to-market goals since processes can be more focused and optimised.

For GM, taking a PLE approach allowed them to optimise their testing process and implement a more focused testing strategy. The company splits half its test system to concentrate on the testing of reusable assets, looking especially at how they go together and into generic products. The other half then follows on with integration testing and specific testing for the different product assemblies.

Ultimately PLE has provided a more efficient and effective way for testing and deploying their testing resources and has provided a more consistent quality strategy to the entire product portfolio.

GM has applied the same decoupling mechanism to their development process and change modifications. Once they have established a design that they are confident will be predictable and repeatable, they move it into on-going factory or production line delivery mode.

Both the coupling and decoupling processes require a fairly extensive management process.

PLE encourages a change in attitude that raises the notion of collective responsibility and group success

PLE requires a necessary change in culture and attitude if it is to be successful. Typically in product delivery, engineers will focus purely on the component that they need to deliver; the leadership often encourages this attitude. In a product line approach the individual product pieces can be relatively small from a development and deployment perspective compared to assembling all the pieces together. Therefore PLE shifts the focus from the individual components to the complete product. In doing so it requires the teams to think beyond their individual responsibilities or that of the individual components to that of the complete product. This encourages them to act more as a single group working on a unified project rather than on the individual disparate components. The positive outcome is a transition to a culture of collective responsibility for success and failure over that of the individual.

PLE reduces complexity and increases the capability for reuse and automation

Core to the PLE framework is the abstraction of product features (software and hardware systems) into reusable assets. Creating reusable assets framed by their feature capability allows for greater cross product awareness. Reuse increases the means for automation and a positive benefit to this is repeatability and consistency, which in turn can translate to improved quality either from the outset or by ensuring any improvements or problems resolved are propagated across all instantiations of the asset. So with very little extra effort, an asynchronous approach to building your software and hardware assets within the context of a specific feature capability so that they are able to be assembled within a product line framework, reduces overall complexity and increases the prospect for reuse. When these are then supported with a testing strategy designed and optimised for reusable assets and integrated deployment, the quality factor is raised even further.

Discussion point #3: The key tools, processes and methodologies that need to be in place to help support effective implementation of a quality focused PLE strategy

Product Line Engineering requires a shift in the way software is delivered and managed within the product delivery process. It also requires a different culture and team mindset. With this comes the need to have the right tools and processes to support both the mechanisms for delivery and management. Getting the right tools and technologies in place can be less challenging than addressing and supporting the “people, processes and culture” change that must occur. The discussion highlighted some important considerations and criteria.

A lifecycle approach to testing

The asynchronous delivery mechanism of PLE requires a testing, verification and validation strategy for every stage of the software delivery lifecycle including that of any subsystems design and implementation requirements. This is necessary to ensure that you have symmetric quality testing activities across the lifecycle stages, i.e. from requirements through to architecture, design, implementation and integration. This explicitly calls for tools that directly support the application of a test-driven focus to the individual stages of the lifecycle and which are then able to feed into a connected management and collaboration platform to ensure that all dependencies are relayed to relevant roles.

The power of test automation

It is also important to ensure that you are able to address variations within unit tests and test cases. As a result, the ability to do test automation is an important plus point as it allows teams to test for multiple variations. There is nothing more powerful than a software team that is able, at the end of the day, to kick start an overnight build of 20 different variations of the software component or system, and then through an automated testing process feed back to the rest of the organisation all the products that would have been impacted by any failures and or improved by the fixes. The cost and time benefits speak for themselves.

A "science versus art" approach towards testing in PLE

There is a need for a "science versus art" approach for testing in the context of product lines. The "science" has to do with a good automated testing strategy. "Art", on the other hand, has to do with minimising the time spent on redundant testing in common areas across multiple products and maximising coverage in testing areas that are truly unique across the product set. Since it's harder to test everything in every product in a product line scenario, the "art" is in the insights needed to identify tests that don't need to be replicated across two or more products where there is a high probability that the behaviour and performance characteristics are identical.

An evolving tool strategy

A PLE platform that focuses on raising the quality of the assets and the delivery process will clearly benefit from a certain level of automation, an integrated tooling framework and collaborative processes to ensure that stakeholders from different parts of the organisation and the product lifecycle are kept aligned. However, few organisations will buy or have the need for a comprehensive toolset that addresses all the end-to-end requirements of a PLE platform from the start.

Specific tooling requirements will evolve over time and will correspond to the maturity of the PLE implementation. The same also applies to the level of automation required and the ratio of manual-to-automated processes employed. Over time your PLE implementation will likely expand, and therefore so will your tooling needs and the level of automation that will be available to you and which your processes are able to handle.

General Motors started with a relatively small piece of development using a PLE approach; this has grown over the last 15 years. At the beginning, their PLE platform consisted of tools that provided a data organising framework. There was little call for automation or abstraction and they found manual processes to be perfectly adequate for their needs for the level of complexity they were dealing with. However, over the course of 15 years, the level of complexity has grown alongside the complexity of the electrification of cars. As a result, they have needed to move into another generation of tools which focus on abstracting information and features into modelling frameworks (e.g. variation and fusion models) that automatically ensure alignment and compliance with data or information held in a central repository/database. In summary, their need for automation grew over time and as complexity increased.

Pragmatic assessment of tooling needs required

Those looking to adopt a PLE strategy need to assess the products they are building, evaluate the level and complexity of the software being used and the size of product line they want to develop for, against the tooling portfolio that they already have in order to identify additional tooling support.

GM found that there were a number of factors which affected the choice of tools required, dependent on the size, complexity and variations of the products being developed.

- The size of the software element or the set of software components in the product will drive the choice for tools that are more database/repository-centred, where the governance and management of large volumes of assets, relationships and dependencies against policies is vital. Tools with management facilities will also be important.
- Deployment support is another factor that will be dependent on the size of the overall product. Delivery of a very large product will slow the amount of automation that can be employed since there will be multiple integration points. Therefore there will be little requirement for sophisticated automated deployment tooling. However, if one is deploying large volumes of products (in the range of hundreds or thousands) with different variation sets (as in the case of mobile phones), then tools for build automation and for handling the size and complexity of the deployment for the assemblies will be key.
- The number of feature variation or different models of product will determine the choice and need for tools that abstract variation models and manage the dependencies.

There may not be the need for a lot of tools at the start, or even a calling for a comprehensive tooling strategy. But as a product expands in the breadth of functionality it is able to deliver and the number of models through which these software feature variations are associated with, grows, any tooling strategy employed needs to focus on managing your future confidence for generating and delivering product variations with consistent and auditable quality.

Discussion point #4: Getting the business to invest in a process for managing software variations that is aligned to the product delivery process and identifying the metrics for success

Engaging business sponsors to invest in a specific strategy or tooling /technology platform can sometimes be a challenge. There is no "one size fits all" approach since the path to engagement will depend on the culture of the organisation.

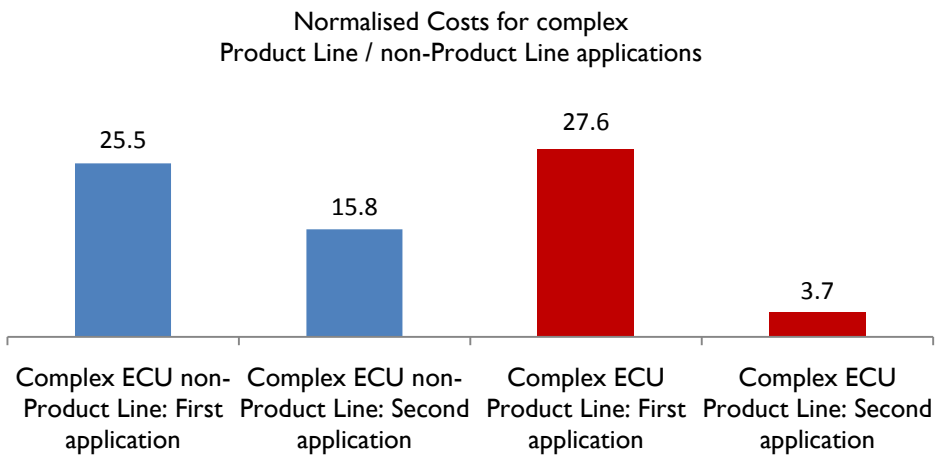
The value of PLE in automotive production is the improvement in quality and the reduction in costs for delivering model variations

Assessing value can be complex. As you might expect, it needs to be expressed in the context of delivering against business goals and solving pain points. Simply asking the length of time a PLE platform will take to process a change would provide the wrong results since it takes longer to process an individual change in a product line implementation than a traditional product engineered environment. This is largely due to the fact that a product line addresses all the different variations. In reality, the value assessment criteria for PLE is the total effort that it takes for the team to execute or deploy a new variation of the product. For traditional product engineering systems and processes the costs are fairly linear since the deployment costs of delivering a second product is often twice as much as it is for delivering one. In a product line delivery model, subsequent deployments of a product variation cost less, although the actual cost efficiencies still need to be measured within the context of the total project cost.

As shown in Figures 2 and 3, GM was able to demonstrate the cost efficiencies of a product line delivery model against traditional methods for both complex and simple applications over a five year roll out period.

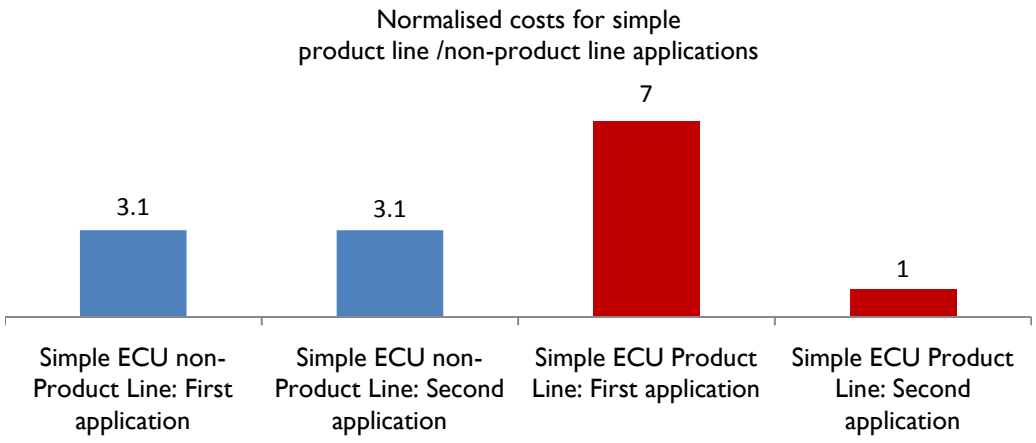
The data collected by GM in both graphs show the reduction in engineering development costs between product line and non-product line products. In both graphs the data is normalised to the smallest costs and based on equivalent ECUs where some were being added to the product line while others were still being engineered as traditional products allowing a comparison to take place. The most important take away point is that by implementing a PLE model the GM team were able to gain significant cost efficiencies with the second version of a product in a product line. In both cases (complex and simple systems) the cost savings were a factor of seven for the product line application.

Figure 2: Graph demonstrating cost efficiencies achieved with product line delivery of complex systems against those of non-product line delivery



Source: General Motors

Figure 3: Graph demonstrating cost efficiencies achieved with product line delivery of simple systems against those of non-product line delivery



Source: General Motors

The trends suggest that further cost efficiencies could be gained with each subsequent release.

Managing and implementing variations without a product line approach will undoubtedly raise the complexity level exponentially impeding both governance and quality management processes and hampering the ability for full traceability. All of this not only leads to the problem outcomes (quality, costs etc.) identified in this and earlier sections, it creates a compliance challenge to regulatory rules and policies that would have detrimental and far reaching consequences if breached.

There is a wealth of supporting data to suit the spectrum of business cultures

There is a wealth of data and literature providing overwhelmingly positive comparisons of costs, quality and other aspects of product line methodologies against traditional delivery methods. Businesses covering the broad spectrum of industry verticals have, through PLE, made improvements and achieved significant savings that would make a compelling business case for the different criteria of business sponsors.

Discussion point #5: The future of PLE driven software development services within the automotive industry, especially in driving innovation and business value

PLE within the automotive industry is driving business and quality advantage and has a long future. Many in the automotive industry have reached a point with their existing processes and platforms where they are no longer capable of dealing with more complexity, more product variations or of handling all the alternative views on hybrid scenarios in vehicles. As a result, they are being driven to stay with the complexity and feature variation limits that they feel comfortable to manage. Ultimately though, complexity is growing fast and an inability to cope with it can critically impede broader business objectives. As a result, many see PLE as a vital strategy for surviving and competing in the demanding nature of the market based on the advances made in and by software technology, as well as in the context of the impact of global economic and environmental issues.