Abstract. This paper presents a “mid-term” return of experience form ALSTOM Rolling Stock on its implementation of Product Line Engineering (PLE). It describes the journey we have undertaken to implement PLE, the challenges we have had to face and the manner in which we are finding our way (most of the time deliberately, sometimes fortuitously) to define a profitable reuse strategy and to structure our approach on PLE. The paper also presents some encouraging intermediate results and concludes with the perspectives and the future challenges in our search for Product Line Systems Engineering excellence.

Introduction

Any company, be it an original equipment manufacturer or a provider in almost any industrial sector, will tell you the same story: they are all constantly striving to deliver better (safer, more reliable, more attractive) products at a faster pace and with high profits in extremely competitive markets. This is no small issue for any organization, let alone for global companies that develop large scale complex systems for the global marketplace.

The transportation industry and the rolling stock sector are no exceptions to this state of affairs. The railway landscape has indeed significantly changed over the last few years. Examples include the European railway operations market (now formally open to competition) or the arrival of new players in the global market (new customers, new operators and new rolling stock providers). Delivering the appropriate product with ever shorter times-to-market and at competitive costs has become the critical factor to survive not only in historically saturated railway markets, but also to get a foothold in new emerging markets. There are many different ways to face this challenge. For most rolling stock providers, it would be unthinkable to manufacture off-the-shelf materials ready to be delivered to a customer well in advance (unless, of course, one is lucky enough or visionary enough to make the right guess). For traditional railway organizations with strong historical backgrounds, implementing a reuse strategy would seemingly be an option of utmost interest because it could allow them to leverage previously developed assets for their reuse into a new product.

This understanding of the concept of reuse is the most widespread amongst common folk: “use again what you have done before to produce the same thing or something similar”. The purpose of reuse, though, might be a little less obvious: “produce the same thing or something similar, only faster and better”; in other words, improve product characteristics, such as quality, cost effectiveness, time to delivery or risk mitigation. This is in line with the definition of a Product Line (a family of similar products with variations in features and functions) and of Product
Line Engineering (PLE), which is “the engineering of a product line using a shared set of engineering assets and an efficient means of production, taking advantage of the commonality shared across the family, while efficiently and systematically managing the variation among the products” (Krueger 2015).

Real life, however, usually looks quite different for large industrial organizations developing many different products in different geographical zones. Incompatibilities of engineering artifacts, inconsistent technical data and duplication of information in different repositories are all common aspects in this type of organization. These practices make reuse very problematic at a cross-company level and hamper the creation of well-structured, corporate-wide product lines. The reason for this is relatively simple: since practically no system is created “from scratch”, engineers are most likely to reuse knowledge from a previous project or product in the form of documents, processes or models. The problem is that this knowledge, albeit optimal in a local context, is very often partial and sometimes even inadequate in a wider context. An engineer who works on the same product year in and year out can “only know what he knows”.

So the problem that arises can be stated as follows: how can a large, global organization transition from a widespread, careless practice on reuse to an effective and profitable implementation of a reuse strategy? This paper presents a “mid-term” return of experience from ALSTOM Rolling Stock on its journey towards Product Line Systems Engineering excellence. Moreover, the paper describes the approach followed for the implementation of product line engineering and gives some encouraging intermediate results as a possible answer to the previous question.

**Building a Profitable Reuse Strategy**

Reuse is a well documented practice in software and manufacturing, where well-known examples of successful reuse can be found, like: configurable software modules, standard software architectures, flexible manufacturing systems or automobile platform sharing (a wider review on automotive production paradigms can be found in Howleg 2008). The origins of PLE as a distinct engineering practice can be traced back roughly to the mid-1970s, when the first works on the formalization of software product families appeared (often traced to the work of McIlroy 1976). But the formalization of this practice for its application to complex systems engineering is scarce and relatively new despite a historical, de facto or casual reuse practice in industry, like the utilization of existing specification documents, technical drawings or test procedures (Fortune and Valerdi 2013), and the existence of some reports on successful industrial applications (Flores et al. 2013, Gregg and Clements 2016).

There aren’t many internationally recognized, established and proven standards or references on the processes, terminology and methodology that an organization can look up to in order to implement Product Line Engineering (PLE) for complex large scale systems. Those that are known in the Systems Engineering domain (ISO/IEC 2015, AFIS 2013) are hardly applicable or lack practical, hands-on guidance for use in a real industrial context. In this situation, probably the best thing to do when attempting to implement PLE is to let common sense be the guide, that is, to apply a little systems thinking. Which means that we should always start with our own needs: we must understand where we are (analyze the current state of our practices) and where we want to go (how would we like to go about our business).

As any initiative dealing with enterprise change, the implementation of PLE usually encounters many barriers. One of the problems is that the acceptance and application of PLE principles are difficult in areas where reuse is not already an explicit practice, as immature as this practice
may be. The bottom line is that any initiative that calls for a more rigorous formalization is always seen as a rigid, burdensome, process-oriented approach that, to crown it all, requires upfront investment and forethought! The same can be said, by the way, of Systems Engineering on which any good practice of PLE should be based.

To increase the likelihood of succeeding is such an endeavor (as suggested in Beasley & O’Neil 2016), the underlying idea would be to gradually turn this negative perception of PLE into a more federating, inspiring and liberating approach that confers to an organization a clear vision of customer needs and the capability to efficiently adapt its products to these needs, leading to a greater performance overall and to more successful results. The key words here are step-by-step and flexibility, to enhance the probability of adoption and application of the PLE principles in all areas of the organization. The most suitable approach to implement PLE in a given organization would be as the result of a thoughtful balance between the specific problem (the type of product, variety of markets, providers and volumes) and the maturity of the reuse practices in place in every area of the organization.

Although we might not be exactly where we would like to be today, ALSTOM Rolling Stock has indeed initiated this gradual transformation. In the rest of this paper, we describe the journey we have undertaken to implement PLE, the challenges we have had to face and the way in which we are finding our way (most of the time deliberately, sometimes fortuitously) to define a profitable reuse strategy and to structure our approach to PLE.

**Beginnings – The Brownfield**

The offer of ALSTOM Rolling Stock is based on a large portfolio of product families. The highest-level criteria to differentiate one family from another are basically the maximum speed of operation and the journey distance (Figure 1).

![Figure 1. Rolling Stock Product Line Chart.](image)

The definition of products at ALSTOM and in the railway rolling stock sector, in general, has always been driven by customer demand, except for some few isolated examples for which a niche product is defined in a “product push” strategy. We can easily categorize products into two types: first, products that usually require light customizations (these would be more aesthetic or style-oriented, like trams or metro products, for instance); then, products that may require more in-depth customizations (for instance, if a customer requires a specific train architecture, like for high and very high speed trains). So, there seems to be a relationship between the speed/journey distance of rolling stock material and its capacity to be pushed into the market. Figure 1 might also suggest that our work is all sorted out for us, that the framework is in place and that all we have to do is simply harvest our existing products and start enjoying
the benefits of profitable reuse. But a picture is not always worth the thousand words of the real story.

**Nobody’s right if everybody’s wrong.** A few years ago, when our first efforts to formalize our PLE practices began, most of the PLE-hampering aspects related to large organizations that we outlined in the introduction were also true for ALSTOM. One of these aspects was the fact that, for historical reasons, the geographical region in which a product was to be sold was considered as another criterion to differentiate our product families, if not the most important criterion. Different sites inside the company ended up having their own “product line” (which they defended fiercely), although they could actually be working on the same type of product as another site.

One consequence of this was that system architectures and technical solutions were quite different, even for the same train function, so that commonality of subsystems or components was very difficult to obtain. As an example, we discovered five different system architectures regarding one of the more (supposedly) transverse train functions for metro products. When questioned about this diversity, every engineer thought of his definition as the best suited for his product, but also as the “reference solution” everybody else should apply. Unsurprisingly, another consequence of this was that, when it came to choosing the type of product for a tender in a new market in yet another geographical region, it was not always an easy task to reach a consensus as to which of the many existing “reference solutions” would be the best suited for the new market.

**Quick wins, long-term losses.** As in other companies with a strong mechanical and manufacturing background, we have been (and still are) confronted by different challenges associated with the definition of a long term vision on reuse and of a strategy for product line engineering. One of these challenges is that, in the minds of most players on a project, reuse concerns only tangible final products (parts, hardware or software components, systems), as described by Wymore and Bahill (2000). One of the problems with this point of view is that it overlooks the fact that a reused product is almost inevitably modified from project to project, introducing variations that are rarely formalized and retro-fed to the product line baseline. In the end, nobody knows precisely what the product that is being reused really is. Another problem is that the activities of the systems engineering processes also produce other intangible work products (like architectures, operational scenarios, use-cases, validation plans, justifications of design choices or even tacit knowledge). Reusing these work products requires upfront reflection and investment in order to formalize and adapt them easily to specific project contexts. We are often confronted by a two Byzantine generals’ dilemma as to what would provide the greater potential profits for an organization: reusing physical parts or reusing non-physical engineering assets? For the moment, we have prudently chosen not to open a debate on this futile question, but rather to let logic advance all the arguments.

Perhaps the hardest challenge to overcome is cultural change inside the organization. In the first place, people (in particular, project management) seem to choke on the initial investment that is required for a profitable implementation of PLE. Nobody wants to put money into something that will yield benefits “sometime in the future” or for somebody else (be it the company itself). Secondly, in many organizations, the money one can reinvest on internal initiatives is pretty much dependent on the income that projects (i.e. contracts with end customers) can produce. And when projects have the power, where is an organization going to put its money? Usually, money goes to the short-term, quick-win, single-product investment, which imposes the management of many product-centric, development-silo projects. The money rarely goes to a long-term investment to build a product line, which would lead to
managing one single, large project for an integrated platform and many small projects sharing (i.e. reusing) many commonalities. The difficulty is that the quantified evidence that is required to support the latter case can only be obtained with sufficient return of experience, although one can easily realize that the effort to coordinate a portfolio of N parallel products with “project-to-project” shared commonalities is proportional to N² (Krueger 2015).

On the technical side, the main challenge can be summarized as “careless reuse”. Common sense would tell you that reusing an engineering asset should be the result of a well-documented decision process. However, it is safe to postulate that one could find examples in many organizations where reusing an asset actually proved to be more costly (if not catastrophic) over the system life cycle than developing a new asset. While the purchase cost of the reused asset might have been low, the overall costs induced by debugging, repair, validation, warranty expenses or penalties slowly but surely ended eating up the originally planned profits. The most common reason for this is that engineers and program managers alike overlook the necessity to perform a thorough, systematic analysis of the new context in which the asset will be reused, which can lead to catastrophic consequences (see the example documented in ESA, 1996). To put it simply, without an overarching reuse strategy, copy-paste alone cannot be considered as PLE (or as engineering, for that matter!) and it cannot yield all the potential benefits of Product Line Engineering.

Sowing the Seeds of PLE

The most important precondition to overcome the challenges exposed in the previous section is that PLE must be understood correctly. If PLE is misconstrued, the significant investments that are required will most certainly result in an underachievement of the expected benefits (the disillusion behind the promise). In today’s organizations, a clear, farsighted vision that defines the purpose of PLE is very rarely defined at the top, then shared all the way down to every layer of the organization. Just like for SE, successful PLE initiatives seem instead to be embraced by a small group of champions and deployed following a middle-out scheme. It is at the heart of the group of champions that stating and sharing the purpose of PLE is of utmost importance, as it helps to orientate all the actions undertaken around PLE. In our case, the purpose of adopting Product Line Engineering for ALSTOM Rolling Stock was clearly stated as “improving our business (our profitability) by maximizing the benefits of reuse”.

The Cornerstone. Most recently, ALSTOM decided to focus its activities on the transportation sector and defined an ambitious strategy aligned with its vision to “become the preferred partner for transport solutions by 2020”, its values and its brand identity. The strategy relies on five main pillars, as shown in Figure 2.

![Figure 2. ALSTOM's 2020 strategy.](image-url)
Our approach on PLE as a profitable reuse strategy is clearly aligned with this vision. Actually, PLE is the main instrument of the second pillar of the ALSTOM strategy (a complete range of solutions) and it is also expected to contribute significantly to other two pillars: value creation through innovation—as engineers do not have to worry about the core assets of a product line, they can work on introducing new added-value assets—and operational excellence—as PLE nurtures the quality, cost effectiveness and time to delivery of products (Gregg et al. 2015). Anchoring the purpose of PLE to the enterprise strategy has provided us with an ideal cornerstone to turn PLE into a more federating approach and to tackle the challenge of cultural change (even if this particular battle is far from over). Yet, since one cannot build a house from the ceiling downwards, we’ve also had to think about the architectural options and on the groundworks that shall guide and support our approach.

**Different Strokes for Different Folks.** When analyzing the reuse practices in place in different areas of the organization, we identified three main approaches or “generations” of reuse (Chalé Góngora et al. 2014): basic reuse (or opportunistic reuse), second generation reuse and third generation reuse (or strategic reuse). These approaches basically differ from each other by the level of maturity and the deepness of understanding of the PLE paradigm. The formalization of these strategies has been very useful to characterize current practices and to design our strategy for a gradual transformation towards PLE. Although our final goal is indeed to reach PLE excellence, we are being careful not to impose a particular reuse approach as a goal for any project or sector, since the choice of a reuse approach depends entirely on the specificities of the situation, on opportunity. Furthermore, we are currently forced to conduct this initiative in a very gradual way in order to avoid (as much as possible) any “self-defense” rejections and to let actors understand and learn about PLE at their own pace, and only then, try to lead them to more mature practices.

In basic reuse, a real product family (i.e. a line of products that has been conceived in order to meet a wide range of needs with alternative solutions) does not have to exist. To meet new customer demands (or Request For Proposals), we identify the product that best fits the requirements and the needs in the customer demand among all previously manufactured or delivered products (Figure 3). Modifications on this product are then carried out to completely fulfill the customer requirements through several iterations. In this “clone and own” approach, the variability of products is not designed nor managed.

![Fig. 3. Basic reuse strategy.](image-url)

In second generation reuse, the product is designed as a family of products by identifying the product characteristics that are subject to variation (called variants) and are either visible to stakeholders (external variants) or to engineering teams only (internal variants). We talk about a 150% product family in the sense that the product family scope is normally larger than what it
would take to build just one single product. In our case, the product families that belong to this generation encompass the system and subsystem levels, with traceability associations between them and associations to the product line variants. To meet new customer demands, a gap analysis is performed in order to identify the set of product characteristics (variants) of the product family that fulfill the customer needs. Based on these choices, a specific product will be configured and instantiated from the family (Figure 4). If some customer needs are not covered by the product family, a choice has to be made to either extend the product family or to develop a specific customized solution for the uncovered needs. The product family and the instantiated projects have independent life cycles, although there might be several synchronization points where the modifications made at either side can be shared and eventually implemented. The product family can therefore be enriched by the return of experience from the several instantiated projects.

Fig. 4. Second generation reuse strategy.

In third generation reuse, repositories of reusable modular assets are used to build a new product. Repositories store both the product family assets and the project (or projects’) assets. The concept of 150% product family described above is also applied to configure a product, only this is done on several layers. The main difference with second generation reuse is the way in which reusable assets are managed. In second generation reuse, there is one 150% product family that manages all the engineering assets it requires, while in third generation reuse, assets are managed independently and can be shared across different product families.

The mechanism to meet new customer demands is similar to that of second generation reuse. The gap analysis and the product configuration through the choice of applicable variants are conducted in a similar way, but with slight modifications. First, the choice of applicable variants is done in two stages: system level variants (the train product is partially decided) followed by more detailed, technical subsystem variants (the train product is fully decided). The second modification is that, based on these choices, the asset repositories will be queried for the best suited “building blocks” from which the final product will be built (Figure 5). If some customer needs are not covered by the product family, a choice has to be made to either extend the product family assets or to develop specific customized project assets. Just as for second generation reuse, the product family and the instantiated projects have different lifecycles but can be synchronized over time, and the catalog of reusable assets can be enriched by the return of experience from the several instantiated projects.
It Takes Three to Tango. If we move a little bit further into the technical aspects of PLE, we can identify the fundamental factors that are enabling us to evolve from an opportunistic (basic) reuse to a more strategic (third generation) reuse approach. There are two essential prerequisites for successfully putting these factors into practice:

- Using Systems Engineering and
- Performing good Systems Engineering.

Satisfying these prerequisites is crucial because the formalization of the engineering artifacts that are used or produced during the different activities of the SE processes is the foundation of strategic reuse. Assuming that all engineering artifacts (and their associations) are properly formalized, we can define three fundamental PLE-enabling factors that will transform these engineering artifacts into reusable assets (Figure 6).

- Describing the product variability of the product line: what product characteristics can vary? The issue here is not the choice of a variability modeling language (there are plenty out there that serve their purpose), nor the methodology to model variability. The real issues here are identifying core assets (or invariant assets) from the variable assets of the product.
line amongst all the engineering artifacts, and managing the formalization of the variability of the whole product line in *one single point of truth*. Czarnecki et al. (2012) and the references therein are useful for a complete overview of variability modeling approaches.

- Expliciting the **dependencies** between variants and engineering artifacts: what assets are affected by variability and how? Assets must be 150%, “variability-ready”, *configurable* assets. That is, they must be *designed for variability*.

- Implementing mechanisms to **configure** products: one must decide on the applicable variants to meet a given need and instantiate the asset repositories according to these choices in order to obtain a stand-alone consistent product. To achieve this, the assets must also be *modular*, that is, they must be *designed for reuse*.

The following section will show how some of the previously explained concepts have been put into practice along with some intermediate results.

**Light at the End of the Tunnel**

When PLE was given a new impulse in our organization, different initiatives were launched in parallel. As in any living organization, the Brownian-like panic reaction to the new stimuli was inevitable. Now that the dust has settled down a little, we are managing to channel this energy and reorient these initiatives into three complementary programs, each contributing to the PLE-enabling elements we have just exposed. The first program consists in formalizing anew our *platform* concepts (or product families). A second program deals with a centralized variability management system and the creation of *catalogs* of train sub-systems, while a third one concerns the creation of reusable asset repositories, starting with requirement specifications and system architecture patterns (the latter is not presented in this paper).

**Harvest Time – Platform Concepts Anew**

For the formalization of our product families, a second generation reuse strategy –including requirements databases, operational concept documents, verification and validation plans, train system architectures and the variability of the product family– was implemented. Figure 7 shows the environment that supports this reuse strategy (Chalé Góngora et al. 2014).

![Fig. 7. Environment for a Second Generation Reuse Strategy.](image-url)
Our first implementations of the second generation reuse strategies differed slightly from the originally planned strategy explained above. The gap analysis was performed directly between the customer requirements and needs expressed in requests for proposals and the requirements of the 150% product family database; these requirements were identified as being affected by one or more variants. The variability model was managed in a specific file and captured (manually) into the system architecture modelling environment. As a result of the gap analysis, a list of requirements to be instantiated from the product family was produced. From these, a combination of variants was deduced and used to instantiate the system architecture database of the product family. This was done by “filtering” the invariant elements plus the variable architecture elements that are linked to the chosen variants, as summarized in Figure 8.

![Fig. 8. Gap Analysis and Product Derivation in Second Generation Reuse Strategy.](image)

This partial version of a second generation reuse strategy was applied to a Metro product line, from which three different products have been derived. Compared to typical “white page” developments, our estimations for the first derived product yielded a reduction of fixed engineering costs in the requirement development process of around 50%, for an estimated 80% carry-over scheme (i.e. 20% of customer specific requirements). The second product was derived in a completely different project context: off shore site, different IT infrastructures and novice users. Yet, the estimated benefit was quite similar: 40% reduction of fixed engineering costs for the same level of carry-over. The third product has recently been derived. Although it is too early to have a precise estimation of the obtained benefits, our first estimations yield a greater reduction in fixed engineering costs for requirements development of about 67%.

**Groundworks Consolidation – Variability Management**

One of the shortcomings of our first implementation of a reuse strategy was the need to provide *one single point of truth* for the variability of our product lines to all engineering disciplines. This variability manager must be able to “connect” to different design environments to affect or configure the engineering assets contained in them, according to the chosen variants that apply to a given product. The first targets of this program were the management of assets for the mechanical design domain and the creation of a catalog of subsystems.

Our variability manager (Figure 9) comprises the definition of the product line variability model (also called “feature model” in literature), including exclusion/inclusion dependencies between variants, and incorporates the necessary mechanisms to define and verify product configurations.
(a) Definition of product variability

(b) Dependencies between variants and engineering artefacts

(c) Mechanisms to check completeness and consistency

(d) Mechanisms to configure products

Fig. 9. Variability Manager and Product Configurator PLEIADE® by Acuity Solutions
The variability manager is currently being used to handle the catalog of train subsystems. The standard solutions that subsystem experts want to maintain and reuse for the different rolling stock product lines are captured in the tool. These solutions are described in terms of their technical characteristics. In this operation mode, the subsystems are configured following the same principle of selecting a set of applicable variants. The subsystem configuration is used to query the catalog, which then proposes the standard solutions whose technical definitions are closer to the chosen configuration. In our first implementation, the selection of variants is determined by the subsystem requirement specification received from the system level, as shown in Figure 10. In the near future, the selection of subsystem variants will be conditioned by the variants chosen at system level.

Fig. 10. Subsystem Catalogs Query Procedure.

Up to now, catalogs have been developed successfully for the major train subsystems. They include the means to identify the variability of subsystem requirements and the technical characteristics of the solution, plus an analysis of the requirements coverage by catalog products (Figure 11) and are orienting projects towards proven Standards Solutions.

Figure 11. Eligible Solutions Comparison Grid with Respect to a Subsystem Configuration.
One Brick at a Time – Configurable, Reusable Assets

To complete the list of PLE-enabling elements, let us illustrate the creation of reusable asset repositories with one example concerning the creation of generic, reusable requirement modules in DOORS™. The objective is to help us move forward towards a third generation reuse strategy. As we stated before, in second generation reuse, the product family manages all the engineering assets it requires (this is how our product families are managed today). Our intention now is to transform this into an ecosystem of asset repositories where assets are managed transversely and shared across different product families, like elementary building blocks. The activities carried out with requirements are a first step towards this (Figure 12).

The principle is quite simple: a generic requirements module is created following a standard structure and “pre-filled” requirements (for instance, a performance requirement with units, but without a specific value). The generic module is configured and then made available for a particular project. Mechanisms to link and verify the consistency of the module content with respect to the rest of the project requirements are also provided. Today, the generic modules are configured manually by the module owner (system engineer, subsystem engineer, domain experts, and so on) by “filling out the blanks” in the requirements statements. Tomorrow, the modules will be configured by the variability manager described in the previous section.

Besides providing us with a nice tool to get a project started much faster, this is also helping us avoid the “white page syndrome”, of which many engineers are victims when trying to get their work on requirements engineering under way. Most importantly, we will (finally) be able to ensure that requirements are referenced consistently and that a given requirement document will look exactly the same, whatever the project.

Conclusion – The future is so bright, we’ve got to wear shades

In this paper, we have presented some of the fruit of our experience on the implementation of Product Line Engineering at ALSTOM Rolling Stock, and we have briefly presented a small sample of intermediate results. Although partial, these intermediate results are very encouraging for us, given the relatively small amount of time and resources that we have been able to allocate to our PLE initiatives. The results exemplify the expected outcome of our efforts and show the path for the things we still have to accomplish: pursue the creation of reusable assets repositories in all domains of engineering, achieve the formalization of the variability of our different product families and promote the sharing of engineering assets across our product line of product families, among other things.

The gains we have reported on the workload of the requirements development process of the products derived from one of our product families have gone from 10 to 6, then to 5 and 3 months. We believe that, with a little more investment in our current PLE initiatives, this
workload can be brought down to 3 weeks! If we allow ourselves to imagine that all of the other engineering activities could benefit from similar improvements enabled by PLE (not only an increase in their effectiveness but also in cost avoidance, thanks to a decrease of non-quality issues by reusing quality-proven engineering assets), then the potential growth in our profitability could attain mind-boggling proportions (see the success story in Gregg et al. 2015). We believe this is possible… After all, the Chicago Cubs have just won the World Series!

Coming back to earth, although today we are following (and will continue to follow) a very flexible approach on product lines, allowing mixed reuse strategies to co-exist, our goal is to move forward towards a third generation reuse strategy because we believe this is the most profitable strategy in our context. So, we need to pursue and defend the programs we are currently conducting. We are presently working on the redefinition of two other product families, one for regional trains and another one for high speed trains. We expect to improve the profitability of all our product families by increasing the (relatively) low carry-over ratios that we have today. This will be possible by enlarging our product families to include (and probably optimize) what we consider today as being “customer specific” needs and solutions. This is linked to the cultural change that is still required to modify the organization’s point of view on our platform concepts (or product lines).

However, we must remain realistic and pragmatic and not fall into the pit of being “more Roman than the Romans” to try and manage every single asset as reusable. For instance, some components are indeed very specific to a customer and should not be defined in advance at the Product Line level without the input from the customer. Trying to define upfront the variability of a component may result into a waste of time when the customer wants to make that component unique (for example, on its design aspect) or when the variability cannot be reduced. Indeed, an upfront, perfectly stable planning of variability is practically impossible to achieve because sources of variability can emerge from the arrival to the market of a new technology or from the result of benchmarking (e.g. an unexpected offering from competitors), for instance. In this case, other strategies are preferable such as defining standard interfaces rather than standard components: compliance with the standard interfaces will ensure that the specific solution will not jeopardize the overall architecture of the system. These specific areas of PLE should be clearly identified and the reusable assets adjusted accordingly.

One of our future actions will consist in promoting a more extended, systematic application of the variability manager across disciplines and domains. This will enable us to make what might look like a small step for technology but a giant leap for the organization: using a simple (decision) set of product characteristics (i.e. variants) to determine in fine a list of consistent mechanical, electrical, electronic and software materials from which our trains will be built. However, even if we succeed in convincing all the engineering domains to apply a consistent management of variability, we would still be confronted by one major technical difficulty that we would rather not solve by ourselves: IT, and tool interoperability, in particular. For anyone starting a journey on PLE, these aspects could be either an obstacle or an enabler. PLE solutions should not be built for IT specialists managing complex Boolean expressions, ignoring the needs of product architects and system designers. Tools should be thought of as assistants that capture design knowledge from experts without any middleman. Moreover, variability management should embed design knowledge and data analysis capabilities to provide information that users can leverage to make informed design decisions. Users should get more information out of the tool than they put into the tool. Today, IT and tool interoperability are important technical setbacks that impede taking full advantage of PLE.
Another aspect that we want to tackle is the improvement of our estimations of the benefits of reuse. Today, these estimations are solely based on a reuse percentage (or carry over) between our platforms and their derived products, and on the time spent by engineering teams to perform their activities. A better, more correct measure of the benefits obtained with PLE, would be to know how many activities do not need to be repeated anymore and how much rework is avoided overall, thanks to a smart reuse strategy. To achieve this, a stronger integration of PLE and Design-to-Cost approaches is required in order to design and develop more accurate cost models. For instance, very few (or none) of the cost structures associated with train components today are directly linked to variability. That is to say, cost models will most probably need to be transformed into configurable reusable assets too, turning PLE into a legitimate, fully integrated approach to develop products across an organization.

Finally, we still have to figure out how to solve our main difficulties: (1) Cultural change, which is a key success factor for PLE. Design for variability requires a very specific way of thinking: it is not the easiest thing to teach or learn. As explained before, the implementation of PLE should follow a step by step approach. And (2) where does our money go to? or how to convince the right people to put the company’s money in the right place?

As for any company engaged in implementing PLE, we need to institutionalize a conscious effort to define and achieve an organizational PLE transition strategy. This strategy will need to infuse PLE-related aspects in the engineering processes and their governance, and in the management of product portfolios and of operations. This conscious effort shall also focus on the development of PLE capabilities and on finding the right people (because persuading someone to do something he does not understand or does not want to do, usually gives very bad results!). The route that lies ahead of us is an extremely challenging one, but should we succeed the future is highly-appealing. Concepts as elegant as Product Line Engineering and Systems Engineering confer something of a “quest for an ideal” to any endeavor to implement them, so we have the distinct impression of participating in a very special adventure.

References


Biography

Hugo Guillermo CHALÉ GÔNGORA, PhD, CPRE, is the head of requirements engineering, train system functional architecture and MBSE for ALSTOM Rolling Stock. He has over sixteen years of experience in Systems Engineering in the energy, infrastructure, automotive and railway industries. His topics of interest include formal methods, architecture description languages, safety-critical systems and autonomous systems. He holds an engineering degree in Mechanical-Electrical engineering, masters in Energy Conversion and Internal Combustion Engines, and a PhD on Thermal and Energy Systems. Guillermo is the chair of the PLE International Working Group of INCOSE.

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