Advanced Product Line Engineering Puts the Auto Industry in Overdrive

Automotive engineering has never had so much complexity to address. Producing millions of vehicles per year – each one comprising thousands of parts and potentially different from the one just before it on the assembly line – is a feat unmatched in manufacturing. Adding to this complexity is a slew of next-generation features that require the seamless inter-operation of formerly-standalone subsystems, and that promise more autonomous operation and higher-level user interactions. Today's vehicles must be responsive to the driver's slightest of intentions, while providing the highest levels of safety and reliability under the most extreme conditions. To meet this challenge, manufacturers have turned to increasingly sophisticated software and electronics, adding yet another layer of complexity as well as the opportunity for expensive and image-bruising defects and recalls.

Product line engineering (PLE) is a recognized discipline within systems engineering that is being applied to the automotive world to address precisely these kinds of complexities. In the terminology of business and manufacturing, automotive manufacturers produce a *product line* – a family of products that populate a portfolio that serves one or more market segments. But in the systems and software engineering realm, *product line* has a more specialized meaning. There, it refers to a family of products that, yes, populate a portfolio and, yes, serve target market segments, but which are also built in a way that specifically takes advantage of the commonality shared across the family, while efficiently and systematically managing the variation among subfamilies and individual products.

Born in the 1980s in the software field, PLE was developed because of the extraordinary savings observed over and over again by engineering the whole product family rather than separately engineering each member. PLE is rife with case studies demonstrating that exploiting the commonality throughout the products' total life cycles can return order-of-magnitude improvements in time to market, cost, portfolio scalability, engineer productivity, and product quality; no other engineering paradigm shift has brought about results remotely rivaling that

In the last decade or so, PLE has matured dramatically beyond its software-only roots. Software is now just one kind of engineering asset that can be part of the equation (or not, if it doesn't play a role in the products) along with things like requirements, design models, tests, documentation, user manuals, engineering plans, and much more. There is now industrial-strength reliable automation, widely used and commercially available, that can turn *descriptions* of products into actual products by configuring those assets consistently and uniformly to support each product being built. The concept of a *feature* (a characteristic that distinguishes products from each other) has assumed its place as the way to describe variation. Features describe the product line (What features are available?) as well as individual products (What features did you choose for this product?).

From the perspective of the PLE field – having earned its wings in software, consumer electronics, telecomm, and other industries – automotive manufacturing represents a new frontier and an unbeatable opportunity to further expand its horizons. In automotive manufacturing, product lines contain millions of products, each one comprising hundreds of complex interacting subsystems, and literally astronomical feature combinations. To a PLE evangelist, it doesn't get any better than that. The opportunities for game-changing improvement are enormous in scope and number.

Conversely, automotive manufacturing is driving PLE to new levels of capability and scale because of complexities that, while new to PLE, are business-as-usual for automakers. Here are some of key trends and considerations in automotive manufacturing that are driving a new age in PLE:

- **Lifecycle-wide integration.** A large automotive company will have made tooling choices for each of its engineering artifacts. Perhaps requirements are managed in IBM Rational DOORS, design models in Sparx Enterprise Architect, tests in HP Quality Center, PLM data in Siemens Teamcenter, the owner's manual in Microsoft Word, calibration parameter catalogs in Excel spreadsheets, wiring harnesses in Mentor Graphics Capital, and so forth. To produce the instantiations for individual vehicles, the PLE tooling has to work with each of these tools and preserve the traceability that exists among the artifacts stored in them. Automotive engineering is driving PLE tools to substantially increase the size of the engineering ecosystem with which they must seamlessly integrate. A compelling example of the payoff is the automatic generation of calibration values. Automakers that customize their on-board software by using calibration parameters to enable or disable functionality on a vehicle will see enormous savings in terms of many fewer people doing tedious work, fewer errors to correct in the field as the result of an incorrectly calibrated vehicle, and a vastly shortened process.
- **Comprehensive constraint capture and enforcement.** With thousands of features and feature flavors to choose from, it's critical to have a reliable way to encode and capture all of the knowledge about illegal feature combinations, knowledge that by and large resides in subsystem engineers' heads. Some of it is obvious – no sunroof for a convertible, please – but much of it is esoteric, detailed, and highly specialized. The PLE tooling has to be able to capture and represent these constraints in an intuitive manner, as well as help document why the constraints are true. Then, it needs to enforce them. Making feature choices for a full vehicle involves many hundreds of selections, and the PLE automation needs to guide vehicle engineers through the process every step of the way to prevent any vehicle from being defined and sent to manufacturing that violates any of the constraints.
- **Support for a product line of product lines (of product lines of…).** Features are designed and provided by dozens of different groups. The tooling needs to support the seamless integration of all of their feature models to build a coherent, consistent vehicle. Features in turn need to be supported by technology packages: Choosing a flavor of a park assist feature requires choosing a specific combination of sensors to feed it. Technology choices in turn need to be realized by specific parts, captured in a Bill of Materials. The PLE tooling needs to support knitting together all of the choices that a vehicle comprises, laterally across the organization as well as vertically down through layers of realization specificity.
- **Options that remain optional right up to manufacturing.** In most PLE realms, products are defined with all choices resolved. In automotive, the notion of a *product family tree* comes into play. Vehicles near the top (representing, say, the platform level) have some choices bound, but many left open, whereas vehicles near the bottom (for, say, a specific brand, model, sales region, and trim level) have most of their choices picked, but still not all.

Options are left open for customers to order, which means that choices need to remain unbound right up until manufacture. Again, the PLE tools have to support this capability.

- **Option bundles.** Options are desirable, but can easily become too much of a good thing. The "combinatorics" of even a small number of unbound choices can swamp the company's manufacturing capability. Variant and complexity management, sometimes in the form of defining option packages and assigning them sales codes, is essential and the PLE tooling must be able to let product line managers define, analyze, and manage those bundles.

New generation PLE automation is already available and in use in the automotive industry, providing today much of what is outlined above. In return, PLE is giving automotive engineering a powerful paradigm shift. Instead of deriving features from a parts list, as has been the mental model for many auto companies, PLE is allowing vehicle engineers to start the design process by considering features first and deriving implementation and realization decisions from those. Features drive parts, not the other way around. This gives everyone in the enterprise a common language, empowers customer-first thinking, and streamlines the design and manufacturing process.

In short, automotive engineering is driving product line engineering to produce new, innovative, higher-capability solutions. In return, PLE is helping the automotive industry bring powerful new automation to bear in the design and manufacture of vehicles to shorten engineering lead times, reduce defects, and slash costs. Each field is changing the other, and both are worlds better for it.

About the author: Dr. Paul Clements is the Vice President of Customer Success at BigLever Software, Inc., the industry's leading provider of PLE tools and services. BigLever is applying its Gears PLE technology at some of the world's largest automotive manufacturers to help achieve the results described in this article.