Watson Internet of Things

The competitive advantage of continuous engineering

Watson IoT™

IBM

Contents

Executive summary

Engineered products are more sophisticated and complex than ever before. What were once simple, standalone mechanical products now derive their intelligence from software and can communicate with the consumer—and with each other. For example, heating and air conditioning systems, lighting and alarm systems for the home can sense and react to their environment, and can be remotely controlled and monitored. One day soon, driverless cars will take people from point A to point B with a few clicks on an app. Engineered products such as these are more than novelties. They can perform critical functions such as notifying users about dangerous situations, determining the cause of vehicle accidents, and monitoring and rerouting city traffic.

Today's products are instrumented, interconnected and intelligent. They can transmit and accumulate data, then use it to improve their performance. The tremendous functional possibilities for such products offer both opportunities and challenges to manufacturers. The ability to generate new revenue through software upgrades and maintenance services is one such opportunity. However, because these products use software, transmit data and are parts of systems of systems and different ecosystems, traditional engineering processes often need to be modified to address their design and development.

Continuous engineering can help manufacturers transform their business models to take advantage of the opportunities offered by these products while enabling engineers to address the challenges of developing them. This paper describes how you can use continuous engineering to develop today's smart products and create the opportunities that can get you on the path to competitive advantage.

Change or be left behind

At one time, establishing market leadership could be achieved solely through beating competitors to market, delivering at lower cost or differentiating based on high quality. In today's era of smart products, however, what were once classic measures of competitive advantage are now expected by

Facts and figures from a connected world

- Nine billion devices around the world are currently connected to the Internet, including sensors, RFID readers, computers and smartphones.
- The number of connected devices is expected to increase dramatically in the next decade with estimates ranging from 50 billion devices to 1 trillion.
- The Internet of Things has the potential to create economic impact of $2.7 trillion to $6.2 trillion annually by 2025.[1]

consumers. For example, Volvo's past claim to fame was the safety of its cars. Now, this product attribute is simply a basic requirement and is no longer a differentiator. Differentiators today lie along the extreme edge of technological enhancements. Devices or products that first meet the ever changing demands of consumers will have the competitive advantage.

Product manufacturers are struggling to stand out in this new world. Companies are betting big on new technologies, especially those that inject products with greater intelligence and sophistication. But, with big bets come big risks. With much more embedded software in these products, design errors can go undetected until after the products have been shipped and sold. For example, thermostats that were designed to anticipate temperature needs have left people freezing in the middle of the night. Vehicles have accelerated unexpectedly and uncontrollably.

These problems are largely a result of the complexity associated with having software-defined functionality, along with extreme levels of connectedness. In fact, the level of complexity can be so high that anticipating and testing all possible system interactions is physically impossible. In addition, manufacturers are creating smarter products designed to "learn" by using information from their operational environment or from data that the products themselves transmit. Such information includes operational and performance data, along with data from other products and systems.

Many of today's products no longer stand alone in the world. For example, consider a lone vending machine at a travel rest stop is the middle of Wyoming. To the consumer, it simply dispenses snacks. But behind the scenes it can do much more. If instrumented with sensors and connected to an IT backbone, the machine can sense purchase patterns, monitor stock and place orders for inventory replenishment before running out of a particular item. This is a simple example, but the concept extends over multiple industries. Some delivery companies, taxi companies and repair and maintenance companies use sophisticated electronics in their vehicles to track workers and plan critical and complicated routes. As a result, the companies can increase efficiency and decrease losses caused by human error. Airframes with networked sensors send continuous data related to airplane wear and tear to the computers of their manufacturers, which enables proactive maintenance and reduces unplanned downtime. The expectation for products to be intelligent, instrumented and interconnected is a reality.

For a better understanding of just what manufacturers and engineers are facing in the world of product development, consider a few examples. The sophistication of products on the market is just an inkling of what is to come. Currently, products are available that enable you to use your smartphone to turn off lights in your house and set the alarm or start your car and set the interior temperature even when you're miles away. You can wear a digital device on your wrist that continuously measures your health and detects changes in pulse rate or body temperature. It then uploads that information to a website that shows you the calories you have burned, the distance you've walked and more.

On a much larger scale, networked roads, trains, taxis, and industrial sensors can send information to systems that manage energy use, guide city planners, streamline emergency services and improve local operations. In a city in Mexico, taxi drivers can use GPS-enabled cell phones to share information about accidents, downed streetlights and other events related to their work. Another example is the Google registry and message board, which takes information entered by first responders and others and uses it to help people locate and communicate with loved ones after a disaster, when ordinary communications break down.

These products might seem like science fiction, but they are either already available in the market or likely will be soon, and represent just the tip of the iceberg for what is coming next. These products present a new challenge, which is how to avoid obsolescence in the midst of rapidly changing operating environments and consumer demands. Manufacturers can address this challenge by designing the products so the embedded software that controls functionality can be continuously improved and updated, even though the products themselves have a much longer shelf life. An example is the health and fitness wearable monitor. The software in the early versions of this device simply monitored and captured health and fitness information. However, newer models are equipped with a software update that not only generates data, but analyzes that data and makes recommendations such as, "To meet today's health goal, you will need to spend 30 minutes on the elliptical machine on these specific settings."

The Internet of Things effect

Smart drill bits (the kind used for drilling for oil and gas) can generate over a million pieces of data per minute of drilling. Big data technologies can share the output of data analysis in the cloud that connects the drill bit to its ecosystem and make sense of the data. How can a company design and test such intelligent, instrumented and interconnected products while minimizing the risk that they will not perform as intended? The interconnectivity is a serious challenge because their successful function depends on something outside the control of the primary design team. They might be connected to other products (machine to machine interconnection), to a supporting ecosystem or to both. These products literally become systems in other systems.

This high level of interconnection is commonly referred to as the Internet of Things and it is used in most major industries (Figure 1). As early as 2013, publications such as Forbes and companies such as Cisco and IBM were declaring that the Internet of Things is really the Internet of Everything and predicting that it will grow 10 times faster than the original Internet.[2]

So how do manufacturers and engineers design for such an interconnected environment—one that is outside of their direct control? Designing for standalone products where the software and hardware are both changing at the same time and where multiple disciplines are required to achieve the final product is difficult enough. However, it is even harder and requires even more collaborative engineering and design when these products must connect and communicate with other products and systems in an intelligent way.

	banking	Healthcare	Automotive	Retail	Transport	E&U
Healthcare	Cash replacement solutions Mobile banking	Paid home care family services	Pay-per-drive car rental	Cash replacement Sensor enabled loyalty cards	Paid alerts travelers Congestion charging	Pay-per-use energy
Optimize	Optimized cash management	ER bed resource management	Component predictive replacement Fleet management	Delivery and stock replenishment optimization Store layout optimization	Smart Cities traffic management Airport management	Delay non-essential supply during peaks loads
Extend	Banking the unbanked Biometrics Smarter subsidies	Life style monitoring	In-car movies, music, games Highly automated driving	Smart vending machines Delivery lockers	Mobility services	Smart home services
Control	Remote ATM management Dynamic authorization	Remote hospital environment management	Remote Drive-train optimization	Store energy management Store parking management Dynamic price management	Crowd management Timetable management Asset management	Remotely control consumer devices

Figure 1: Major Industries and the Internet of Things

As product development speeds into this future of continuous data transmission, interconnectivity and frequent software upgrades, manufacturers are left to determine how to continue driving revenue with a business model that appears at odds with this new world. The future is never guaranteed. However, current trends point to new opportunities for manufacturers, such as managing and optimizing the increasingly important processes that happen after the product is delivered to the customer. The world is already seeing these kinds of service relationships. Netflix offers entertainment as a service and Dropcam provides video recording as a service. In IT, instead of relying on hardware sales and software purchase, companies are paying as they go to use software or infrastructure or even platforms and business processes.

Therefore, rather than solely relying on the sales of their products, manufacturers can profit from the product long after it has been sold. Because smart product functionality is provided primarily by software, manufacturers can sell capability upgrades after the product is in the market. For example, the "infotainment" system in a car is likely to need upgrading every few months, even though the car might be on the road for 10 or more years. Providing additional capabilities gives manufacturers the opportunity to "own" the customer. Obsolescence offers the temptation to try another product from a competitor. However, if a product does not become obsolete, the customer is satisfied for a longer period of time, which can lengthen the amount of time a product drives revenue.

Another significant way smart products offer opportunities to increase revenue is based on the data they generate. This data can enable manufacturers to use analytics to predict maintenance needs, which can lower the cost of keeping the product functional. As a result, manufacturers can transform their business models to add a service focus. They can deliver service for a lower cost, which is a "win" for them and their customers. Customers do not have to worry about maintenance, and manufacturers can charge more (or profit more for an equivalent charge) for the service aspect of what they deliver.

So, how can manufacturers start taking advantage of these opportunities? How do these products get made? The answer to that question involves considering how the product originally came into being, what its functions are and how it can be designed to participate effectively in the Internet of Things. Not only must the product generate data, but it must also be the right data that will support the purpose for building the product, such as serviceability. And, the product operates in a complicated environment, one that is changing continuously and unpredictable, and it must be flexible so it can adapt to advances in technology and changes in customer sentiment. Therefore, engineers must be able to understand and model how the product, often a complex system of systems, interoperates in an ecosystem, which is yet another system. The complexity is immense, and systems engineering principles are required to effectively design for operability in this environment.

Concepts and visions are emerging that can help manufacturers address the challenges of changing their business models and developing products that generate the right data and are part of a complex ecosystem. One concept, in particular, can enable companies to move from traditional engineering and product lifecycle management processes to those that are more suited for developing today's smart connected products. This concept is called continuous engineering.

Success through continuous engineering

For manufacturing companies to enjoy competitive advantage in the era of smart products, their engineers need help with the complexity of designing systems of systems. Traditional engineering practices are no longer enough. The more complex a product or system is, the less likely a traditional engineering process will be effective. Producing in separate phases—usually requirements definition followed by design followed by building, then test and so on—creates stops, jumps and breaks in the process. Designers, application developers and others involved in product development often must wait for additional information before they can continue, and often that information is locked away in a system they cannot access or is in an email they did not receive.

Working in parallel with lots of feedback loops can result in bottlenecks and delays that are not supportable in an environment where demand has accelerated. In addition, developing smart products includes learning as you go, which creates change throughout the process. To prevent stoppages and address the change, the engineering process should be a continuous flow that allows for and even welcomes feedback, learning and change. This process should enable product engineers and developers to:

- Integrate and analyze data that crosses the boundaries of traditional engineering disciplines such as software, mechanical, electronics and others.
- Verify that the system is working appropriately before expensive physical products are built for testing.
- Run different types of analysis when traditional testing is not enough for certification or complexity.
- Handle multiple and different requirements, along with tens to hundreds of product variations in parallel.

The goal is to deliver the right products at lowest cost and as fast as possible, removing inefficiencies and misassumptions along the way. In a nutshell, because change is constant, engineering can never stop. Successful manufacturers must be able to engage in continuous engineering.

Continuous engineering is an enterprise capability that speeds delivery of increasingly sophisticated and connected products by helping businesses to evolve their engineering practices to adapt to the accelerating pace of business change. The world can change during the engineering process and manufacturers and developers must be agile enough to absorb the change and keep moving. When the rate of change was lower, businesses could engineer and release products before a major change occurred. Today, however, change is constant. Continuous engineering is the practice of persistently applying engineering tools, methods and techniques in sufficient frequency to address this change.

Continuous engineering is an enterprise capability that speeds delivery of increasingly sophisticated and connected products by helping businesses to evolve their engineering practices to adapt to the accelerating pace of business change.

Continuous engineering isn't "continuous" in the sense that it is never ending. Rather, it addresses the ever present need to rethink, redesign, reintegrate and reinnovate products and systems. It is about helping engineers work in the ways that they want to work—with easy access to all the tools, data and expertise they need to do their jobs better. In a constantly evolving ecosystem of continuous product improvement, engineers can eliminate the costs of unnecessary reinvention, along with high downstream costs, while taking advantage of cross-discipline decision-making and collaboration.

With continuous engineering, engineers are able to operate without being burdened by too many different systems to use, learn and update. Instead, streamlined systems work together and serve the engineers better. The flow is seamless from need to concept to design. Continuous engineering frees them to design and develop the products that can drive revenue after they are sold with upgrades and service delivery.

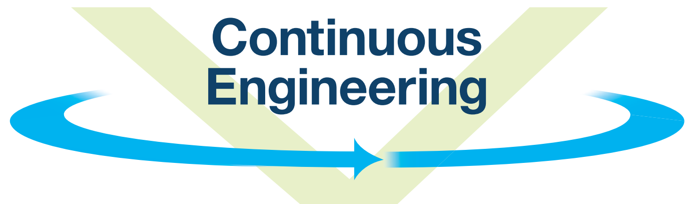

Figure 2: Continuous engineering addresses the ever present need to rethink, redesign, reintegrate and reinnovate products and systems.

Figure 3 illustrates how continuous engineering supports continuous design evolution in the context of the Internet of Things. In its simplest form, the Internet of Things is a “thing” (a product) that generates data that can be acted upon by processes, people, businesses, a combination of the three, or all three. Continuous engineering ensures that engineers can access and use the data generated by the product to make the right decisions. It also ensures that customer sentiment and market data can be used by engineers to create the right requirements for the product design. And, it enables the continuous delivery of product improvements to the market, either by software updates or product releases.

At the core of continuous engineering are three initial practices. The first is **unlocking access to and understanding of engineering knowledge and information,** regardless of source, to enable the right decisions at the right times. The second is the **continuous verification of requirements and design** at all stages of the product development lifecycle to prevent rework and enable the release of a higher quality product to the market faster. And, the third is **strategic reuse across the engineering lifecycle** to increase design efficiency, engineer product lines and tame complexity. With these practices, you can start infusing continuous engineering into your product development. As they spread throughout your teams, you can employ them in larger continuous engineering transformations down the road.

These practices are not new. Understanding the information you are working with, verifying the work you have done and reusing design assets whenever possible have long been recognized as good ideas for getting work done. But in a continuous engineering environment, these things become vital to success. The good news is that your development teams do not have to throw away what they know and do. Rather, they can focus on improving the areas that will gain the most value from continuous engineering.

Everything is becoming connected…

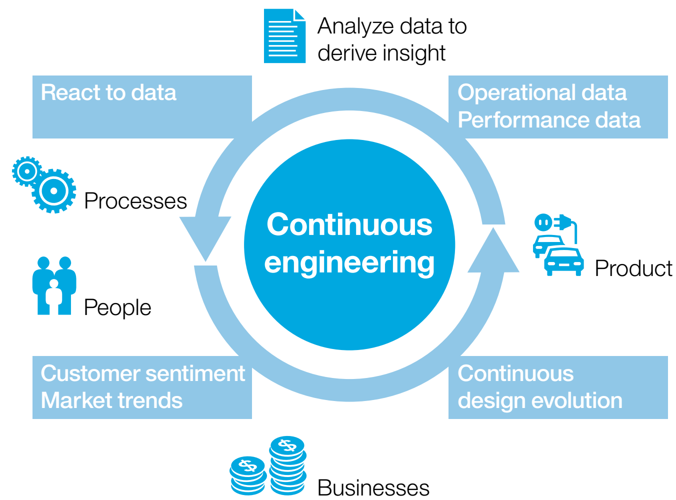

Figure 3: Continuous engineering fits in an ecosystem of constantly evolving products and the Internet of Things.

Unlocking knowledge: A sample scenario

A product manager is in the process of defining a new variant of a mobile phone intended for a set of carriers in a new geographical market. A search for "carrier regulations Korea" returns important content from an index and the web that helps the product manager specify the new variants. The product manager can link the discovered external content to the newly created product definition to ensure that essential knowledge is captured and available to those on the team who need it.

Unlocking engineering knowledge

Your engineering organization has significant amounts of unique, hard-won knowledge and information that are locked in systems, databases, emails, documents and other places. Your organization also uses dozens or hundreds of tools and applications and they all collect data that they store in their own formats and their own databases. Not all of these formats and databases are easily accessible. When critical information cannot be accessed or shared, the end result can be delays, sub-optimal decisions or even failures.

Simple solutions have been suggested and used to try to address this inaccessible information. For example, one school of thought is to take all the documents, specifications, designs, drawings, requirements, code and other assets and put them in a massive centralized database. The problem with the big database starts with the data. Product engineering generates massive amounts of data, much of it in huge files and formats. For example, you currently have unstructured data that you are storing throughout your servers, the cloud and other repositories. These include CAD drawings, blueprints, diagrams, video, emails and more. That does not even include the unstructured data that any third-party stakeholders and development teams might have stored. How would you move all that data, especially when, much of the time, you cannot even access it?

Significant amounts of unique, hard-won knowledge and information are locked in systems, databases, emails, documents and other places. Dozens or hundreds of tools and applications collect data, storing it in their own formats and their own databases. Most are not easily accessible. When critical information cannot be accessed or shared, the end result can be delays or even failures.

Even if you could find a simple method for moving the data, you would still have to build and deploy the database. You would have to search the systems and databases of different organizations for the data you need and translate the data into a common format so it could be entered into the database. And in the process, you could easily lose critical relationships that exist between various data elements. Furthermore, use of a monolithic repository prevents engineers from using tools that most effectively support their engineering disciplines.

For successful engineering, accessing the data wherever it is currently housed makes more sense. This strategy preserves critical relationships. For example, in the case of a fighter jet, if a safety standard changes, you should be able to access data that tells you which requirements are affected. If a new variant is required only for France, the question could be which parts can no longer be reused.

Accessing engineering information

Open standards exist that facilitate connecting to information. The principle is to treat data as linkable in the manner that a URL on a web page links to another web page. Think of a powerful search similar to that of a web-based search engine and queries that enable engineers to ask questions and use impact analysis to support their engineering decisions.

One mechanism for linking to data uses the Open Services for Lifecycle Collaboration (OSLC) specifications, whereby query and manipulation tools can reach into linked data—all of it, not just what might be in a specific vendor's tool. OSLC enables data, work items, tools, designs and other information to be linked without creating a huge, unmanageable repository. The items remain in their original repositories and are linked the same way that one page links to another on the web. "Open" is the operative word in this standard. OSLC is driven by the OASIS open standards consortium and includes open specifications for various disciplines, including Application Lifecycle Management and DevOps. Solution oriented, it is defined by scenarios and inspired by the web. And, an index of engineering data is created from federated domain tools. This index allows for cross-domain lifecycle queries that span engineering disciplines, lifecycle phases (requirements to test and manufacturing) and multivendor applications. But it's about more than access; it's about turning this data into usable knowledge.

Big data analytics

Much of the data (as much as 85 percent) in an organization is unstructured. Therefore, big data analytics can be used to increase the understanding of the plethora of engineering data typically associated with the design of a complex product. This data could exist in databases throughout your organization or it could be performance data generated by the product in operation. Increased understanding can be achieved in several ways. Many times, engineers just want to understand data relationships; for example, what software is associated with what hardware. At other times, data visualization in a familiar structure (for example, ISO26262) is required. Analytics can help identify trends or inconsistencies that humans cannot detect.

How you can adopt unlocking engineering knowledge

How can you get started on unlocking engineering knowledge for continuous engineering? You should explore solutions that link engineering artifacts regardless of vendor, tool or version. World-class tools on a common platform should make it possible to access engineering data where it is stored. Your solution should also include capabilities for analyzing engineering relationships and their impact on the entire design lifecycle. These capabilities should work across or even eliminate tool boundaries to unlock engineering insight. In addition, your organization should offer the capabilities for enabling collaboration that spans engineering domains. And finally, you need a solution that will turn proactive insights from big engineering data analytics and operation data into outcomes and exploit patterns found in big data to optimize product engineering.

Virtual models enable early verification and validation before building anything real

Virtual models can be used for early analysis and trade studies of functionality, behavior, architecture, structure, performance, reliability, safety and more. These models can:

- Abstract mechanics, electronics, software entities, a combination of two or all three, whether they are operating independently or are integrated.
- Test the system being designed along with its test bench (plant models).
- Enable you to use system-level use cases for analysis.
- Offer various configurations to drive ongoing analysis.

Continuous verification

The cost of product failures can be very high. For example, a missile test recently failed, and that failure is likely to cost the manufacturer hundreds of millions of dollars. Had the cause of the failure been discovered much earlier, the cost would most likely not have been anywhere near that high. Consider also the automobile recalls in the last few years. The manufacturers could have avoided incurring the high costs if they had been able to detect the problems in the equipment and fixed or replaced them before any customer drove off the lot in the car.

With continuous verification, physical and systems behavior is modeled early in the product development lifecycle. The simulation and test technologies then continue to be applied in successive stages until the design is mature. In early design stages, change is frequent. Therefore, understanding the impact of proposed changes not only on the immediate product design, but also on requirements and tests is imperative. This process iteratively assembles the contributions of multiple engineering disciplines so integration issues are uncovered early.

But continuous verification involves more than just simulation. It also includes validating that the overall intended function for the product is proper given customer sentiment and market trends.

Verifying continuously

The design of a manufactured product usually has an initial elicitation of user needs and requirements. In some cases, these can be massive documents and in others, they can be use cases from marketing or the business. Verification has to do with conformance to those requirements. One aspect of verification is testing to determine whether the requirements are met by the product or a component. When this process is done toward the end of the development cycle and a problem is discovered, reworking or reengineering the product or component is a significant undertaking. Developers and designers might have to go through most of the design process again to address the issue.

Verifying continuously, by contrast, tests the product and its components throughout the development process instead of only near the end. In the early phases of design, some of the hardware and software might be simulated, which enables testing before everything is developed. In addition, engineers and others integrate different combinations of parts and test after each integration. Continuous verification has been a practice for a number of years in software development. Application developers try to build the entire software project every day and then try to make it run every day. They can discover flaws in the software sooner and correct them sooner rather than persisting until the software is installed and then finding out it does not work.

Validating continuously: Keeping the customer in the loop

Validation is the process of determining whether the right product is being built. Independent of whether it meets the requirements is the question of whether it meets the customer's needs. The two are not the same. Products have been built that met all the requirements yet the customers were not able to use it or it did not work for them. Continuous validation shows the system to customers and clients throughout the development phases and validates that it continues to meet their needs. Because the customer and engineering teams learn as a project or program evolves, validation includes elaborating requirements in more depth over time and ensures that the system being developed continues to be on target. Validation can be accomplished in a number of ways. One way uses early prototype demonstrations; another uses simulations to give customers an idea, before the product is built, of what it will be like. The customers can provide feedback on that and so on.

Validating continuously is not limited to customer demonstration. It is an ongoing process of keeping the customer in the loop. It also involves collecting social content from customers by traversing blogs, social sites and more on the Internet and on websites. Analytics are then used to derive an understanding of how customers feel about the existing product in the market.

How you can adopt continuous verification

To adopt continuous verification, you should seek out a solution that enables you to demonstrate requirements coverage by testing. This solution should automate testing and test management as much as possible and include alerts that indicate when a test fails or a requirement changes. Your solution should support a model-driven approach for requirements and design by using model-based systems engineering for requirements specifications and system-level modeling for architecture verification. And, finally, simulation capabilities are critical—both virtual hardware and virtual software. These include multidomain hybrid simulation, integration of multiple platforms or components from different companies in the supply chain and "verification by simulation"—software, hardware and cyber physical.

Strategic reuse

In the early days of manufacturing, most products were built exactly alike. A good example is the early Ford automobile, which was only available in black. Manufacturing only one variant of a product is economical and efficient because no changes in processes are necessary to accommodate different configurations; however, that one version is not likely to appeal to or meet the needs of every potential customer. At the other end of the spectrum, aerospace manufacturing has evolved to enable product variance to specific customer requests. This form of manufacturing, however, becomes expensive as each product is customized from the ground up. Only customers with very deep pockets have been able to afford this kind of customization. Now most customers want specialization but without the high cost.

In today's manufacturing, many products have a high degree of commonality. For example, an American version of a fighter jet and the British version have a great deal of overlap. Only a few percentage points of difference between them is likely to exist, so engineering two fighter jets from the ground up is not practical. Instead, the core of the jet, or the capabilities that overlap, should be engineered in common, and the capabilities not in common should be engineered separately. The same may be said about updates to a car. Engineered separately are the parts that define the difference between the standard edition, the luxury edition or the parts that differentiate models made for different countries and so on.

Automotive company practices product development efficiency with reuse

A major European automotive company was seeking ways to deliver new models to market faster while lowering development costs. Key to achieving this is more reuse of components that span vehicle platforms. As part of a global excellence program, the company implemented cross-brand modular design of powertrain and parts. As a result, the company has reduced its global engine platforms from eight to three without altering any of the typical brand characteristics.

Strategic reuse is the practice of planning, design and execution so that intellectual capital is used as much as possible throughout the product development lifecycle. The benefits of this strategy are evident when you consider the number of variations in many products. For example:

- Car product lines. A car has dozens of major variants.
- Mobile devices. 900 variants of smart phone platforms exist.
- Aerospace. Almost every customer has a designated variant.

Strategic reuse enables engineering from sets of features with dozens, hundreds or even thousands of product variants. You manage product component versions and their combinations, and, in many cases, you manage a product line.

From ad hoc reuse to strategic reuse

Many different ways exist for promoting the reuse of engineering assets. One type of reuse historically has been “clone and own.” Clone and own means that assets are copied and then maintained by the new owner. As changes are made in the original or the new copy, they are not easily propagated because often the number of times the clone occurred is not tracked, nor is where the cloned assets are located. This method also does not scale well, so more efficient means of managing and reusing common assets in a product line are required.

Defining a cross-domain product structure that facilitates component reuse in multiple different products is another example of reuse. In a cross-domain product structure, you create and manage product configurations for all domains: requirements, tests, work items and other assets. Traceability, navigation, querying and reporting are all supported. If an engineering problem is discovered in one version or a core component, automation enables the fix to be propagated (and traced) to the other versions that are affected.

Fundamental strategic reuse levels

Engineering product line architectures designed for reuse can be accomplished any number of ways that are not exclusive to one another; they can be mixed and matched and customized for particular needs. However, three patterns are common:

- Multi-stream variant management. The first, fundamental pattern provides the core mechanism of configuration management, which involves multiple engineering disciplines and tools. The capability uses product and component versioning to create configurations that represent different product variants in the product line or a different release of a product in the product line.
- Parameterized reuse. The second pattern uses parameters to automate the creation of product variants. These parameters enable you to conditionally include components in product definitions and to apply parameter values to specific engineering artifacts. At this level, the reuse of artifacts is accomplished by maintaining a single source of the product design without maintaining manual branches.
- Feature-driven product line engineering. The third level applies feature models, which involve expressing sets of features and their relationships instead of all the details in the designs. Core assets are created and organized in combinations. From them and the core architecture, you derive additional products. At this point, you create a feature variability model for the platform and then map features to the products. Feature selection enables you to derive component configurations.

In all of these patterns, the versions and variants apply to all engineering information, which includes the requirements, designs, simulations, calibrations, tests, change requests and more. These activities reduce the engineering effort level but maintain the same level of customization, which is the goal with strategic reuse.

How does all of this work? Consider a company that manufactures container ships for shipping companies in countries all over the world. Among these ships are one for a United States company and one for a Chinese company. The company has reused some components from the US container ship for the Chinese container ship. In a product line model, engineers for the company abstract a core platform from the commonalities between the two ships. The engineers draw from that core platform to create the one for a Mediterranean shipping company, one for a Japanese shipping company and one for any other markets the company sells to. Any changes to a core component will propagate to the ships for all markets.

How you can adopt strategic reuse

To adopt strategic reuse, you should seek out a solution that helps you implement reuse patterns optimized to your particular market, product and business strategy. It should offer configuration management of requirements, designs, simulations, calibrations, tests and implementation artifacts. It should also enable you to define the variation in your product line and evolve it over time.

Get started with a technology leader

Continuous engineering is a broad and enticing vision. Engineers are not constrained by tools, infrastructure or access to information; instead, engineering is a seamless iterative flow between need, concept, design, simulation, manufacture and test. Collaboration and knowledge sharing between engineering disciplines is effortless. As a result, thinking, creating and sharing have no boundaries, and the focus is on the work, not tools.

IBM is committed to this vision and has technology and platforms in place to help manufacturers achieve competitive advantage in the era of smart products. IBM was one of the pioneers of Open Services for Lifecycle Collaboration (OSLC). OSLC is at the foundation of IBM's commitment to continuous engineering; however, other technologies have been developed to enable the vision. IBM® Rational® Engineering Lifecycle Manager is a query and data manipulation tool that can reach into linked data—not just IBM data and tools, but also other tools from other vendors and even tools that you have developed in house. Engineers can discover information from across your enterprise to gain new insights and context to support engineering decisions.

IBM has also combined a broad set of capabilities to develop a platform for continuous engineering. Connected, integrated and indexed, this open solution helps facilitate interaction with existing product development technology investments. It also includes the latest technologies for social media and big data in a product development application. Manufacturers of smarter products can achieve rigor, speed and completeness and manage compliance more nimbly than in the past.

IBM's vision and platform for continuous engineering can be used as the building blocks for transforming your business model to one that accommodates initial product sales, continuous customer engagement and service delivery. These building blocks can be used to put you on the path to this transformation and guide you through the processes necessary for achieving competitive advantage in this new world of manufacturing and engineering.

Conclusion

Manufacturing has changed for good. Differentiating your manufactured and engineered products from those of your competitors is more of a challenge because, often, what were once differentiators are now expectations. Also, software plays a much bigger role in innovation—in most cases, driving it—and meeting customer and consumer expectations. In addition, products are generating data that is being accumulated and stored in the cloud and hardware, and that data can be used to improve performance and lower the costs of maintenance. As a result, manufacturing is careening full speed ahead toward a world where the services you offer can drive revenue along with the sales of your products.

Transforming your business model to one that includes services is a tremendous undertaking. Because the concept of delivering services and software as the key to manufacturing success is still in its infancy, getting started can seem overwhelming. Continuous engineering can help. Continuous engineering is an enterprise capability that speeds delivery of increasingly sophisticated and connected products by helping businesses evolve their engineering practices to adapt to the accelerating pace of business change. The objective is to make sure that no gaps remain between the designed system and real-world requirements.

Continuous engineering has three initial practice areas: unlocking engineering knowledge, continuous verification and strategic reuse. These engineering practices can put you firmly on the path to continuous engineering and competitive advantage. IBM has developed a platform for continuous engineering that can help you incorporate these principles as part of transforming your business.

Success in today's competitive manufacturing environment requires integration that spans the entire development lifecycle for traceability and collaboration, and it requires analytics to understand the implications of change. The time has passed when companies could operate with islands of engineers and tools and their data—it is time for continuous engineering.

For more information

To learn more about continuous engineering, contact your IBM representative or IBM Business Partner, or visit the following website: **ibm.com**/continuousengineering

Additionally, IBM Global Financing provides numerous payment options to help you acquire the technology you need to grow your business. We provide full lifecycle management of IT products and services, from acquisition to disposition. For more information, visit: **ibm.com**/financing

Footnotes:

1. McKinsey Global Institute, 2013. "Disruptive technologies: Advances that will transform life, business, and the global economy. McKinsey and Co., May. Accessed from http://www.mckinsey.com/insights/business_technology/disruptive_technologies

2. Evans, Dave, 2006. "The Internet Of Everything: Where Technology And Innovation Meet To Make The World A Better Place," Forbes, 14 Nov. http://www.forbes.com/sites/skollworldforum/2013/11/14/the-internet-of-everything-where-technology-and-innovation-meet-to-make-the-world-a-better-place/

Software Group
Route 100
Somers, NY 10589

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