Enabling innovation through integrated systems engineering

SIEMENS

White Paper

Create, capture and deliver a systems perspective through integrated lifecycle processes and cross-discipline synchronization.

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Executive summary

Systems engineering is fundamental to profitable outcomes

While innovative new products can contribute to revenue growth, profit margins increase when companies push for innovation in the product-related systems and processes that are fundamental to the way things work.

As products become increasingly complex, companies must develop and master the interplay among elements of vastly different natures. Consider the mechanical, software and electronic systems that have been incorporated into today's airplanes, automobiles, home appliances and cell phones in an effort to delight customers with the latest functionality.

As more integrated components and subsystems contribute to the final product, manufacturers must become adept at integrating all of the activities involved in their design, development, test and production to ensure a successful and profitable outcome. These principles apply to any "system" of interrelated elements – whether those elements are components of a physical product or assets deployed in a mission-critical process or ecosystem.

However, many companies tend to look at products and processes within the context of distinct elements and development stages. The software applications that companies typically implement reinforce this thinking. Yet to respond to market demands and achieve profitable growth, companies must quickly demonstrate expertise both in terms of executing each of these disciplines and in successfully integrating them into their core business.

Companies that apply a systems engineering approach are better able to achieve this goal and to address the rapidly escalating integration issues that are driving up costs and reducing profits.

At the highest level, systems engineering is a discipline applied at the start of the development process to establish the features, functions, interrelationships and outcome requirements for any physical product or for any ecosystem. It ensures that all requirements support the initial strategic intent and are communicated to all downstream decision makers through integrated requirements management.

Product lifecycle management, or PLM, solutions that support systems engineering enable companies to model various scenarios and alternatives and to evaluate the impact of potential tradeoffs on time, cost and quality.

As the development process unfolds and experience is gained through execution, systems engineering incorporates lessons learned and best practices in a continual process of improvement. It captures the logical, physical and functional information in a common repository that can be accessed by all contributors across organizations and disciplines and throughout the entire product lifecycle.

A robust, digital PLM environment facilitates this approach by enabling companies to manage all functions, interfaces, logical designs, requirements and design data – including mechanical, electrical, electronic and software data – both as individual subsystems and components of a product and as an integrated whole.

This paper discusses fundamental areas that need to be addressed if manufacturers want to establish a systems engineering approach to decision making throughout the product lifecycle:

Create a systems engineering environment

Establish a systems engineering approach to model and evaluate the development of all products, processes and their related elements in order to balance the requirements and constraints of multiple disciplines and components and to achieve the desired outcome.

Connect requirements through enterprise data management

Synchronize and manage cross-disciplinary requirements that define features, functions and interactions required to achieve development goals. Continuously communicate requirements and changes across the value chain and throughout the lifecycle, from inception through ongoing maintenance.

Integrate test and validation for systems designs

Early in the development process, pretest and prevalidate all aspects of the product together as a whole system.

Create a systems engineering environment

As complexity increases, so does the risk that performance and profitability goals will not be met. The more complex an environment is, the greater the risk associated with defining, describing, modeling and configuring it when conditions are fluid. The greater the interdependence of systems in new defense strategies, the more coordination, modeling and analysis of their interactions is required.

Likewise, the more complex a product is, the greater the risk associated with planning, developing, manufacturing, marketing, selling and sustaining that product in a highly competitive global marketplace. The introduction of mechatronic systems that combine mechanical, electrical, electronic and software components in recent years (such as automotive anti-lock braking systems (ABS), SLR cameras and aerospace "fly-by-wire" systems and subsystems) has only compounded the problem.

By helping companies to understand a system or system of systems as a whole in terms of established business and engineering metrics, systems engineering enables them to proactively manage and orchestrate all system- and subsystem-level elements and to drive fully informed decisions throughout the product lifecycle.

To establish the foundation for systems engineering, companies need to focus on a systems approach:

A systems context for lifecycle processes

It is imperative that companies apply a systems engineering approach at the front end of the development process and sustain it throughout the lifecycle, driving it into each of the disciplines involved in realizing and sustaining the product or ecosystem. To facilitate this, companies need to apply systems engineering concepts from a top-level definition of systems architecture to a fine-grain level of design and production.

For example, product development teams must be able to collaborate on a systems-level product architecture by capturing multiple product views, including views of the product's features, functions, physical content, interactions and logical hierarchy across the value chain. Early on, systems engineers must assess the potential re-use of existing product knowledge. They also must address cross-discipline and cross-platform tradeoff issues that are likely to arise, in addition to program constraints that need to be met in order to satisfy the product's business objectives.

The design of highly automated production processes requires an understanding of the interactions among all systems (including specific functions and hand offs) required to achieve the desired outcome. By modeling all components of the production process along with their interfaces, companies can identify constraints and define appropriate product, process and workflow requirements.

By enabling a comprehensive understanding of the product or ecosystem early in the design process, a systems engineering approach enables companies to drive up profitability and minimize costly changes down the road. When all of the disciplines involved in the lifecycle have a complete understanding of the system as a whole, they can use that knowledge to better optimize the tradeoffs that drive detailed design, manufacturing, sourcing, sales and service decisions. This requires connecting systems engineering with execution so that everyone involved in lifecycle processes can make decisions from a systems-level perspective, consistent with the initial strategic intent.

Pratt & Whitney reduces support equipment and labor requirements by half

Among the world's leading suppliers of aircraft engines, Pratt & Whitney takes a systems engineering approach to its design process. In an industry first, the company's PLM systems allowed Pratt & Whitney to develop a fighter engine and associated support systems at the same time. Assemblers and flight line mechanics participated in the engine's design from inception. The result is ease of assembly, maintenance and repair. The engine has 40 percent fewer major parts than similar engines and each part is more durable. The engine reduces requirements for support equipment and labor by half, and will require 75 percent fewer shop visits for routine maintenance.

Connect requirements through enteprise data management

Today's global enterprises work with suppliers and strategic partners around the globe. This complicates the development process and requires effective communications in order to avoid downstream delays and costs. An effective systems engineering approach is required to ensure that decisions, requirements and changes are effectively communicated across these distributed teams.

By integrating requirements management within an enterprise data management framework, companies are able to communicate requirements consistently throughout the entire process, from ideation through testing and analysis. This requirements-driven environment should support automated documentation to validate compliance and regulatory issues. In addition, comprehensive change-management capabilities that alert all contributors to the impact of changes throughout the lifecycle must be in place along with feedback loops that provide field performance data.

When built on a PLM backbone, systems engineering solutions enable companies to centrally manage all components, systems and subsystems as individual elements, in addition to managing the whole. Such an environment ensures that authorized team members work from the same set of assumptions. It facilitates enforcement of security measures and access rights, to prevent users from accessing or modifying a requirement that is already being accessed by someone else. These solutions also provide the ability to digitally validate downstream processes in a closed-loop process at the point of design. By including all components and processes in revision control, engineering workflows, change management and configuration management, companies can dramatically improve the success of new products.

Within an optimized systems engineering environment, product teams capture and define all of a product's market, regulatory and design requirements and relate these to fine-grain design elements and performance targets that can be tracked and updated throughout the product lifecycle. This should include managing all relevant designs and variants, product specifications, models (including 3D simulations) and test results. With this in place, product requirements can directly influence the processes that cross-discipline teams employ when making and executing design decisions.

Systems engineers also can build regulatory requirements – such as end-of-life recycling regulations or hazardous waste treatment and recovery practices – into the product lifecycle and thereby turn design-for-compliance into an implemented reality. Similarly, they can connect Six Sigma goals into early stages of the product lifecycle, which is particularly valuable when companies "hit the wall" at 4-Sigma and need a real-world boost that improves quality overall.

Systems engineering ultimately produces a structure linking requirements to system and subsystem structures and to product structure. This mapping of product and technology is a key to success as, when done correctly, it directly links high level product strategy to detailed development and manufacturing execution.

Systems engineering brings key decisions to the front of product development

A leading provider of advanced weapon and space systems with approximately 15,000 employees across the U.S. launched an initiative to transform itself from a collection of distinct and geographically dispersed operations into a highly efficient enterprise running on a unified digital PLM platform. Recognizing that decisions made early in the product lifecycle account for 90 percent of a product's costs, the company implemented systems engineering methodologies to push all key decision making to the front of the product development process. It has established common processes and best practices that pull the entire organization into a lean virtual enterprise. Requirements specification, capture, traceability and management have improved company-wide, enabling the company to realize significant cost savings.

Links to downstream processes are essential for effective systems engineering. Once product teams have established the connection between requirements and their engineering designs, they have a unique level of visibility that enables team members to understand which requirements are affected by a design change or which design elements are affected by a requirements change. This linkage extends the product development organization's change-management capabilities by ensuring that standardized workflow processes are automatically triggered (e.g., to inform decision makers about a change impact) whenever any requirement or design change occurs – thereby facilitating comprehensive revision control on an enterprise basis.

An enterprise PLM solution provides the capability to communicate requirements and to collaborate as a unified team. Advanced, web-based data consolidation tools and executive dashboards collect and visually present a wide variety of product requirements, including customer needs, market study results, regulatory restrictions, engineering standards, company-specific policies and quality specifications. When these are maintained in a common data repository, companies ensure that all contributors – regardless of where they are located – can access the most current, accurate product and process information.

When properly implemented, the requirements management process identifies, quantifies and analyzes a documented set of product expectations that can be traced back to their original sources. This level of requirements traceability plays a crucial role in enabling cross-discipline product teams to align their decisions with the product's strategic intent, as well as ensuring compliance with all customer and regulatory requirements.

Systems engineering applies to all phases of development

NASA Jet Propulsion Laboratory (JPL) is the leading U.S. center for robotic exploration of the solar system. NASA JPL approaches product development as a hierarchy of systems and applies systems engineering at all phases of system development. JPL views the role of systems engineering as that of delivering to management a fully developed, certified system that meets user requirements. This includes such activities as defining requirements, developing alternative designs, allocating performance margins and allowances, supporting 'super-system' development (resolving interface problems), overseeing subsystem engineering and coordinating system certification.

Integrated test and validation for systems designs

Few companies today have adequate tools to support testing and validation for complex products, processes or ecosystems. Most business support systems offer basic milestone lists and little more. Few testing and validation tools are connected to overall workflow, let alone to detailed design and manufacturing or production systems.

It is difficult enough to test and prevalidate every aspect of a physical component that has no moving parts. From a systems engineering perspective, the challenge is not simply to ensure that everything that comprises a product – mechanical parts, systems, subsystems, components, electronics or embedded software – or that all assets in an ecosystem are functioning properly. More importantly, systems engineering requires that everything that goes into the end product must be tested and validated together as a whole system. Testing and validating each component or part (including interfaces among subsystems or software components) must be conducted in concert with every other component, and it must be done as early as possible in the development process.

PLM enables companies to validate systems design, investigate alternative concepts, identify tradeoffs and access performance data throughout all stages of the lifecycle using digital simulation, verification and validation tools. These tools also provide testing and validation information across all relevant disciplines and organizations across the value chain, enabling domain experts to understand how their elements perform within the context of the whole product, process or ecosystem. By testing and validating all product elements virtually, companies can reduce development costs, minimize production errors and increase quality.

Simulation in virtual mode also helps ensure that important information is available in time to influence design and manufacturing decisions. This reduces risk and helps to eliminate downstream costs caused by compressed schedules or last minute change orders. A robust digital environment enables companies to evaluate all of the potential the impacts of change. When all systems are integrated through this environment, contributors can be alerted visually of the unintended consequences of their decisions. For example, by changing the required stopping distance of a vehicle, a virtual environment shows the ripple effects on the thermal characteristics of the brake system, as well as a potential violation of the hydraulic fluid rating, potential failure modes in sensors or changes in the ergonomic feedback from the brake pedal to the driver.

Finally, the systems engineering environment needs to facilitate collaboration across global enterprises, including suppliers, customers and strategic partners. For manufacturers, this means that OEMs, plants, manufacturing engineering firms and manufacturing contractors must work interactively in a process-centric, collaborative environment that forms a continuous cycle of manufacturing development and improvement.

Conclusion

As companies strive to achieve profitable growth through product and process innovations, they are recognizing that traditional approaches to development must be replaced with a more comprehensive, systems-level approach. Innovative products in every industry are rapidly becoming more complex in response to customer demand. Processes and ecosystems are becoming more complex and fluid. As a result, new product development encompasses many more disciplines than ever before, from hydraulics to software, electrical, control, networks and environment-control systems (HVAC).

To ensure that innovative new products contribute to profitable growth, companies must identify and resolve integration issues much earlier in the product development process and much more efficiently than in the past. At the same time, they need to continue to support their current business practices even as they transform their processes and demonstrate expertise in new disciplines.

Successful companies are introducing systems engineering concepts early in the development process and addressing the rapidly escalating integration issues that are driving up costs. They recognize that design synchronization, data management and diverse design processes are fundamental reasons that they can't rely on product development "as usual."

Many companies are familiar with systems engineering principles at the platform level. Today's business environment requires that they practice these principles more broadly and establish a comprehensive systems engineering approach to managing the entire lifecycle of any product, process or ecosystem.

This requires an enterprise-wide PLM environment that can incorporate and manage cross-disciplinary information and processes. PLM enables companies to involve all stakeholders from all disciplines in a coherent development process that gives users visibility into the whole system. As a result, companies can flow requirements throughout the product development process and synchronize multiple disciplines. Potential problems relative to specific product configurations can be identified early on, enabling teams to better quarantine issues and manage risk. The impact of change can be evaluated across subsystems, components and functions, so that downstream costs can be controlled.

An integrated systems engineering approach enables companies to determine and act on the key issues identified in this paper, specifically:

- What the product, process, system or ecosystem will do and how it will behave by architecting the whole product with computer-aided engineering tools in a systems-level engineering environment
- Who will be informed by creating an enterprise-wide data management environment
- How the product, process or ecosystem will be developed and delivered by communicating the correct set of requirements and constraints
- When the desired objectives have been achieved and what methods will be used to prove it through testing and validation

By providing these capabilities, systems engineering can directly boost a company's innovation capacity. Equipped with a virtual, integrated view of the whole system, or system of systems, companies can review new elements with customers and drive demand ahead of the competition. Ultimately, a systems engineering approach prepares companies to achieve their time-to-market, cost and quality goals as they transform their process of innovation.

About Siemens PLM Software

Siemens PLM Software, a business unit of the Siemens Industry Automation Division, is a leading global provider of product lifecycle management (PLM) software and services with 6.7 million licensed seats and more than 69,500 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software works collaboratively with companies to deliver open solutions that help them turn more ideas into successful products. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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