Siemens PLM Software

Teamcenter for Systems Engineering

A holistic approach to understanding complex products and reducing business and engineering risk

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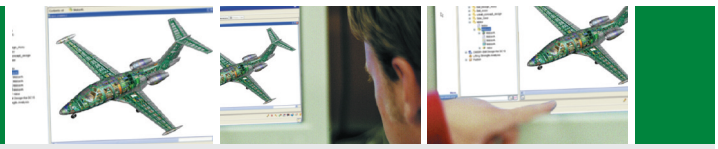
white paper



Teamcenter® systems engineering solutions enable companies to account for a product and its related lifecycle processes from multiple business and engineering perspectives. This "whole" product understanding allows organizations to synthesize/analyze interdependent product relationships and manage the product's related engineering and business risk.

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Executive summary

If you understand a product in its entirety as well as the processes used to plan, develop, manufacture and sustain it – and if you can monitor and measure the relationships between these processes – you can systematically mitigate program risk and materially improve a product's chance for achieving marketplace success.

Product complexity and business risk. *Complex products raise the stakes for today's product makers. It is safe to say that the more complex a product, the higher the risk associated with planning, developing, manufacturing, marketing, selling and sustaining that product in a highly competitive global marketplace.*

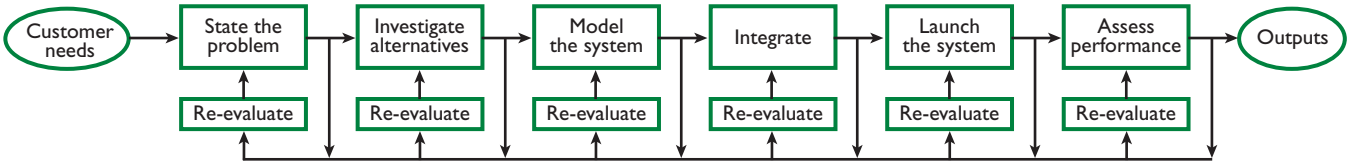
- *If a product fails to meet customer expectations, its marketplace acceptance will be dubious at best.*
- *If a product fails to conform to established regulatory requirements, product makers face the potential of heavy non-compliance penalties.*
- *If early concept design stages are not coordinated with the downstream stages in the product lifecycle, start-overs, redesign and rework can result in a runaway project.*
- *If engineering changes are not properly aligned with requirements, a program's strategic objectives can be lost in the shuffle.*
- *If bad design decisions are not caught upfront or if their impact is misunderstood, rampant redesign can result in unnecessary development cost, as well as in one unsatisfactory workaround after another.*

This level of complexity is compounded by the need for today's product makers to implement improvement initiatives for new product development, value chain synchronization, enterprise data management, commonization and re-use, knowledge and intellectual property management, regulatory compliance and production efficiency.

Managing complexity through systems engineering. *Siemens PLM Software believes that the way to comprehensively address this level of complexity is to apply systems engineering techniques when implementing each of your improvement initiatives – as well as when accounting for the gaps between these initiatives.*

Teamcenter – Siemens' comprehensive portfolio of digital lifecycle management solutions – provides systems engineering capabilities that enable product makers to assess the effectiveness of their product initiatives from multiple engineering and business perspectives. By allowing companies to understand the whole product and all of its related lifecycle processes in terms of established business/engineering metrics, Teamcenter's systems engineering solutions allow system and subsystem level elements to permeate and drive decisions throughout the product lifecycle.

Why systems engineering matters. *The goal is to enable every stakeholder in a product program to recognize that their decisions impact everyone else who participates in the product lifecycle. Equally important, Teamcenter's systems engineering solutions facilitate impact analysis and tradeoff decisions. The result is optimized products that balance the effect of multiple business and engineering considerations, including market appeal, product cost, performance, manufacturability, safety, disposability, regulatory compliance, usability, maintainability and total quality.*



The systems engineering process

Siemens PLM Software solutions. *Siemens provides the following kinds of solutions to address the eight phases of the systems engineering process defined by the International Council on Systems Engineering (INCOSE) fellows.*[1]

- Systems architecture definition *provides total program visibility so that systems engineers can define the problem statement and decision makers can leverage systems-level metrics to make optimized tradeoff decisions.*
- Requirements management *enables product teams to capture and define all of the program's market, regulatory and design requirements and relate these requirements to fine-grain design elements and performance targets that can be tracked and updated throughout the product lifecycle.*
- Systems level engineering *enables development teams to model the system from the "top down" and integrate its subsystems and components "upfront" so that every discipline can fully understand the impact of their product decisions. This level of derivation enables developers to break the product system into different configurations with different assemblies and different versions that represent all of the variations that arise, including product variants, options and add-ons that can be developed to extend the profitability of the program.*
- Systems investigation, simulation, verification and validation *enable product developers to validate system design, investigate alternative concepts and assess product performance at different stages in the product lifecycle.*

This white paper concentrates on Siemens capabilities for systems architecture definition and requirements management. Other publications address Siemens solutions for systems level engineering and systems investigation, simulation, verification and validation.

[1] A consensus of INCOSE fellows endorses The Systems Engineering Process from A.T. Bahill and B. Gissing, "Re-evaluating Systems Engineering Concepts into Systems Thinking," *IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews,* 1998. This model defines the systems engineering process as being comprised of eight phases that account for the problem statement, alternative investigation, system modeling, subsystem/component integration, system launch (validation), performance assessment, reevaluation and variations.

Multiple levels of business risk

Product development complexity carries the potential for substantial financial and marketplace impact.

- Catching design problems on the factory floor costs 10 to 100 times more than catching them during the design process.
- Between 50 to 70 percent of all new product ideas that make it to market will fail[2], usually because the new product did not meet customer needs, or its quality was too low, or the product was late to market.[3]
- The cost of regulatory compliance is increasing exponentially, as evidenced by the fact that U.S. companies planned on spending $15.5 billon dollars on regulatory compliance in 2005 and $80 billion between 2005 and 2009.[4]
- Studies indicate that the dispersal of design, engineering, manufacturing, marketing, sales and service activities around the world have produced an environment where "a clear majority of...value chains lack the capabilities to effectively generate new products."[5]
- Industrial design has become a key differentiator for all product categories – and a discipline that is capable of generating organic growth, new revenues and wider profit margins. Ignoring this reality can severely impact company performance in the battle for market share.
- Failure to capture, understand and keep up with project requirements results in runaway development costs 70 percent of the time.
- Many companies have invested millions of dollars implementing Six Sigma quality objectives only to discover that they have hit the 4-Sigma quality wall. Failing to deliver that last 2-Sigma improvement inhibits companies from reducing the cost of quality by as much as 25 percent of product sales.

[2] *Spending in an Age of Compliance*, John Hagerty and Fenella Scott, AMR Research.

[3] AMR Research, 2005.

[4] *Mastering Innovation: Exploiting Ideas for Profitable Growth*, Deloitte Research, 2004.

[5] Ibid.

Multiple improvement initiatives

Today's product makers face a complex set of challenges in delivering and sustaining their product offerings. These challenges test the mettle of multiple value-chain participants. Each set of participants is expected to master a disciplined body of knowledge. Each discipline (e.g., industrial design, engineering, simulation, tooling and machining) champions a particular series of business initiatives. Each business initiative is empowered by a specialized set of applications.

Today's product makers are particularly concerned with business initiatives that offer enormous potential for revenue generation, innovation, quality and productivity improvement, including:

New product development, where companies integrate the voice-of-the-customer, metrics-driven requirements, project management techniques and R&D planning methodologies into their product development processes to improve product innovation.

Value chain synchronization, where companies attempt to lower their operational costs, access specialized centers of excellence and improve localization by adopting a distributed product development strategy that enables globally dispersed value chains to collaborate effectively and align their daily work processes.

Enterprise data management, where distributed value chains that operate under different business rules exchange and share their product information while securing these assets and retaining their organizational autonomy.

Commonization and re-use, where product development organizations re-use common platforms, proven parts, equipment and automated processes to create cost efficiency and implement best practices.

Knowledge and intellectual property management, where information captured from multiple application systems is created and maintained at its source while being made available to multiple programs and their entitled users for continuous product and process innovation.

Production efficiency, where companies enable their product development and manufacturing organizations to share information and interact collaboratively to facilitate total quality, Six Sigma and Design for Six Sigma objectives.

Regulatory compliance, where product developers validate product compliance with multiple regulations in a single environment that captures regulatory requirements and material/substance data from multiple sources.

Role of systems engineering

As effective as these improvement initiatives are individually, they do not provide product makers with a holistic approach that accounts for the gaps and inter-relationships between each initiative – nor do they account for *other* business and engineering issues that influence marketplace success or mitigate program risk.

Siemens believes that systems engineering provides a metrics-based methodology that companies can use to assess their products from multiple engineering and business perspectives. By understanding a whole product and all of its related processes, companies can address an inclusive range of strategic issues as they plan and execute their product programs.

The Institute for Systems Research has established eight criteria for defining systems engineering's distinguishing characteristics, including the ability to:[6]

- Account for cross-discipline considerations
- Leverage high-level metrics
- Represent hierarchical structures
- Facilitate global and local optimization
- Reflect the role of heterogeneous influences
- Accommodate dynamic behavior
- Apply process and product lifecycle methodologies
- Consider the impact of non-technical components/metrics

Siemens provides a variety of solutions that meet all of these systems engineering imperatives and, most importantly, provide the "glue" for bringing these imperatives together. Siemens' understanding of the role of systems engineering and the implementation of its capabilities starts with the following definition:

> *Systems engineering is comprised of a broad set of processes and methods that model and analyze the interactions between a product's requirements, subsystems, constraints and components.*

As this definition indicates, it is crucial to apply systems engineering at the front end of the product lifecycle (where decisions are made about what is being built), as well as throughout the lifecycle and into each of the disciplines involved in realizing and sustaining the product. In essence, companies need to apply the concepts of systems engineering from a top-level definition of the systems architecture to a fine-grain level of design – thereby providing a "neural network" for facilitating systems engineered products.

Siemens' Teamcenter solutions integrate systems thinking with systems engineering across the entire product lifecycle by enabling organizations to capture and deliver a systems-level perspective to everyone engaged in the product development process. The idea here is to recognize that every product decision has implications for everyone who participates in the product lifecycle. It is strategically crucial to understand these implications and communicate their impact so that product stakeholders are able to optimize *multiple* business and engineering considerations – including the product's market appeal, cost effectiveness, manufacturability, safety, disposability, regulatory compliance, ease of use, maintainability and total quality. Just as importantly, product makers need this level of understanding early in the product lifecycle before change becomes too costly or too late to make a marketplace difference.

In essence, Teamcenter facilitates the following accepted systems engineering conventions.

- Teamcenter balances the cross-discipline influence of *multiple* engineering, manufacturing and business factors that not only affect the process of product realization, but also the product's marketplace success and the effectiveness of its service and support organizations.
- Teamcenter places a high priority on *measuring* the optimization of the product lifecycle at its highest levels of integration. Typical systems-level metrics that Teamcenter actively measures include the cost of manufacturing, time required for design/development, a wide variety of lifecycle metrics for reliability, re-usability, maintainability and human factor analysis and many other quantitative considerations.
- Teamcenter leverages metrics to compare and improve both product technology and process performance – by emphasizing how all of these factors fit together from an overall perspective. Teamcenter approaches systems engineering by synthesizing these engineering and business elements into *higher-level models that can be hierarchically assessed and monitored.*
- Teamcenter's systems engineering solutions facilitate both *global* and *local* optimization, thereby enabling stakeholders to improve the product and its realization processes as a whole – as well as improve the performance of such granular elements as the product's parts/components or a single process' related work tasks.
- Teamcenter enables companies to understand and improve the product *dynamically.* By leveraging product lifecycle management (PLM) to account for all of the product lifecycle's evolutionary stages, decision makers can determine how the product and its processes vary over time. Just as importantly, Teamcenter is adept at accounting for and synthesizing the impact of *multiple* changes, including market, regulatory, design, manufacturing and service/maintenance changes.
- Teamcenter's approach to systems engineering emphasizes the importance of *process* improvement by injecting holistic product knowledge into individual processes whose workflow can be streamlined, automated, measured and compared during both product planning and product realization.

[6] "What is systems engineering?" *An Introduction to Systems Engineering.* The Institute for Systems Research, 2005, www.isr.umd.edu.

Real-world use cases

Teamcenter for Systems Engineering has proven its credentials in numerous real-world deployments.

A subsidiary of one of the world's most widely known medical products companies wanted to double its revenues without increasing the expenses associated with managing a complex supply chain. The company uses Teamcenter's requirements management capabilities to provide each of its R&D teams with a common repository for capturing and tracking device requirements. The company also uses Siemens' computer-aided systems engineering capabilities for architecture capture, modeling, interactions and interfaces – enabling them to perform tradeoff studies and what-if analysis to determine and refine individual product requirements.

An internationally renowned aerospace and defense company uses Teamcenter's connected requirements and quality documentation capabilities to comply with U.S. Department of Defense guidelines and U.S. International Traffic in Arms Regulations (ITAR). Key capabilities allow product teams to communicate program requirements to downstream decision makers, as well as provide the audit trails and automated processes required to satisfy controls at the program level.

One of the world's largest automakers uses Teamcenter's requirements management capabilities to drive its global engineering teams, manage requirements for multiple vehicle configurations and track compliance to ensure that regulatory requirements are met. Key capabilities include the ability to share requirements throughout a global engineering enterprise, facilitate requirements traceability and configuration management and manage vehicle, system, subsystem and component technical specifications for the quality documentation program.

The diesel engineering division of one of the world's largest manufacturers uses Teamcenter to track compliance to established standards and requirements. "We started out hoping to track requirements and compliance to standards…we weren't looking for cost savings…what we got was returns (that were) immediately recognized by purchasing." By sending early connected requirements to their suppliers for bid (rather than waiting for the design process to begin), the company realized 10 to 15 percent savings before bidding started – and another 10 to 15 percent during the bidding itself.

Summarizing Teamcenter's systems engineering solutions

As the accompanying table indicates, Teamcenter provides two key capabilities that companies can use to apply systems engineering to the development of complex products.

Capability	*Advantages*
Systems architecture definition	Teamcenter's Systems Architect enables companies to implement a systematic and repeatable approach to systems engineering during the planning stage of the product lifecycle. Systems Architect enables decision makers to understand each product being developed in its totality by defining the product's strategic intent and relating it to the market, regulatory and design requirements that the product is expected to achieve, as well as to the product's program constraints.
Requirements management	Teamcenter's Requirements Management capabilities allow companies to capture and manage a complete set of product requirements that are traceable back to their sources. Teamcenter enables product developers to link these requirements to fine-grain design elements. These connected requirements can then be updated, audited and analyzed in terms of their development-related impact through every stage in the product lifecycle. In addition, Teamcenter's compliance management solutions enable companies to capture material and substance data from different suppliers and validate this information against requirements set by national and international enforcement agencies.

Systems architecture definition

Teamcenter's Systems Architect provides a unique web-based environment that product teams can use to capture, analyze and improve the product development cycle using systems engineering techniques. Systems Architect's holistic capabilities enable decisions makers to view and quantitatively evaluate products in their entirety so that tradeoff decisions can be effectively made on a systematic and repeatable basis.

In practical terms, Systems Architect enables product teams to create a systems-level product architecture by capturing multiple product views, including views of the product's features, functions, physical content and logical hierarchy. Systems engineers typically allocate/partition the product's functions into system elements and subsystem interfaces that establish a basis for defining "what" is being built. Early on, systems engineers also identify a product's opportunities for re-use, as well as cross-discipline and cross-platform tradeoff issues that are likely to arise and program constraints that need to be met to satisfy the product's business objectives.

Systems Architect facilitates the creation of an interdisciplinary environment with web-based groupware, collaboration and information-linking capabilities that decision makers can use to:

- *Model a product and its related processes into high-level hierarchies.* Typically, systems engineers use Systems Architect's graphical building blocks to create hierarchical structures that represent a product and its processes from multiple system-level perspectives including high-level product structures, program-related organizational assignments, manufacturing process views, project management perspectives, cost analyses and documentation views.
- *Provide whole product visibility.* Once the product and its processes are modeled as hierarchical structures, systems engineers can use Systems Architect's linking capabilities to interrelate these views together to provide a whole product perspective that planning, project management, development and manufacturing teams can leverage for cross-discipline optimization.
- *Leverage linked product requirements.* Teamcenter's Requirements Management solution enables product teams to capture requirements documents from multiple sources, parse these documents for individual requirements and allocate these requirements to fine-grain design elements within a Teamcenter-managed product configuration. The integration between Systems Architect and Requirements Management enables systems engineers to incorporate these connected requirements into whole product views to facilitate both global and local optimization.
- *Establish quantitative program constraints.* Systems engineers also can leverage Teamcenter's Requirements Management solution to link the product's system-level hierarchies to quantitative program/project constraints. These constraints define metrics that should be tracked and reported across the development cycle. To facilitate this, systems engineers attach "budgets" and "calculated properties" to both high-level and fine-grain engineering and business factors. These budgets and properties establish controls over such business factors as cost, resource allocations, work functions, system functions and scheduling limits – as well as engineering controls over such factors as performance, reliability, throughput, material/substance restrictions and many other considerations. Most importantly, these connected constraints enable product teams to understand the interdependent relationships that exist between different aspects of the product and how these relationships impact one another.

- *Reflect non-technical concerns.* Systems Architect enables development team members and suppliers to attach "project notes" at both the system and fine-grain levels to explain their design intent, record their concerns and raise issues of interest that should be addressed by other participants in the development cycle.
- *Automate and activate processes.* Project administrators can attach "activators" at the system and fine-grain levels to automate specific processes and activate given behaviors. Activators can function as event triggers and alarm warnings that can be communicated in real-time to groupware communities. For example, team leaders can specify that Systems Architect inform all review team members whenever a "crucial" requirement is changed and initiate a procedure that asks them to review/approve each related change.

Systems Architect provides a graphical user interface that systems engineers can use to represent products, processes and systems around building blocks they already understand. Users employ graphical icons to represent components, products, requirements, budgets, project notes, documents, hierarchical relationships and other product-related elements.

In turn, users can build higher level "systems" by linking these icons to one another. Users can "classify" these building blocks by assigning attributes to given icons or sub-typing these graphical elements. Uses can "activate" these systems by describing a building block's behavior and attaching it to a simulation model – as well as by capturing a Teamcenter-managed workflow and relating it to a system.

A variety of other unique capabilities also distinguish Systems Architect, including the ability to:

- *Link "parent" elements together,* which enables product teams to understand relationships between a system's various building blocks (for example, by linking a car's chassis to its drive train, team members are able to understand the relationship between the chassis and the transmission).
- *Leverage groupware techniques in a process-driven framework,* which allows product teams to capture documentation as a by-product of a design/development process.
- *Employ Visio as a user interface into Systems Architect,* which enables teams to capture Systems Architect's high-level views through a standard diagramming tool and then leverage the relationships between a product's requirements, design elements and diagrams to make certain the enterprise's diagrams always reflect the current design state.

Requirements management

Teamcenter's Requirements Management capabilities allow product teams to define, capture, engineer, manage and leverage product requirements that originate in multiple sources and make them available for enterprise access/usage through a single Teamcenter-managed source of PLM information.

Typically, companies use Teamcenter to collect a wide variety of product requirements, including customer needs, market study results, regulatory restrictions, engineering standards, company-specific policies and quality specifications.

In Teamcenter-managed systems engineering initiatives, the requirements management process identifies, quantifies and analyzes a documented set of product expectations that can be completely 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.

Traditionally, product makers created and managed their product requirements from diverse sources, including spreadsheets, custom-built databases, linked documents and document tracing tools. Unfortunately, these sources usually resulted in *isolated requirements* that ended up in documents that never were read, in databases that could not be linked or in applications with daunting user interfaces that had nothing to do with product development or the product lifecycle.

Teamcenter changes the way companies manage product requirements by enabling product teams to capture and organize diverse kinds of requirements in a single web-based environment that users can access using tools they already understand. Teamcenter provides "live" Microsoft Office integrations that support requirement viewing/editing through Microsoft Word, Excel and Visio. This capability essentially elevates standalone Office applications into multi-user applications that are connected into an enterprise environment.

The Teamcenter environment ensures that entitled product team members are working from the same set of product assumptions, while protecting the integrity of those requirements by locking out anyone who tries to access/modify a requirement that is already being accessed by somebody else. In essence, the Teamcenter multi-user environment enables users to view and work on requirements concurrently in a controlled way, rather than serially passing requirements – which is typical in conventional word processing environments.

Teamcenter's Requirements Management solution is unique because it enables product teams to connect requirements to fine-grain design elements managed by other Teamcenter solutions. By tying requirements to Teamcenter-managed designs, documents, product specifications, models and test results, product requirements are able to directly influence the processes that cross-discipline teams employ to make and execute design decisions.

Along these lines, teams can "build in" 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, quality teams can use Teamcenter's Requirements Management solution to 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 *upstream* – as well as downstream.

Once product teams establish the connection between requirements and their engineering designs, team members have unique visibility that enables them to understand what requirements are impacted by a design change (or conversely what 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.

The accompanying table summarizes key capabilities that distinguish Teamcenter's Requirements Management solution.

Key Teamcenter capabilities for requirements management

Capability	*Business value*
Requirements traceability	Product teams can leverage Teamcenter to establish a complete set of product requirements that are traceable back to their sources. This capability is especially valuable for supporting regulatory compliance, where product makers need to show regulators how their products – and substances, materials and components that comprise them – meet specific compliance thresholds at multiple levels.
Web application	The web-centric nature of Teamcenter's Requirements Management solution allows entitled users to access product requirements through standard internet browsers. The groupware nature of these capabilities ensures that all team members work from the same set of requirements with access to reports and Teamcenter's viewing and editing capabilities in real time. Since each requirement, function, property and relationship in a hierarchical Teamcenter product view has a unique web address, product teams can create web-based processes to leverage every product requirement, inject these references in documents and emails, and directly respond to routed review documents and change requests.
Windows desktop interface	Teamcenter's Requirements Management solution is fully integrated with common Windows desktop applications, including Microsoft Word, Excel and Visio. Users are able to understand and leverage product requirements through desktop applications they already understand. Similarly, Teamcenter-managed requirements can be exposed into a real-time Teamcenter community collaboration environment so that invited team members can navigate requirements documents, edit these requirements and use the community's discussion threads, routing facilities and action item lists to support requirements-related tasks and assignments.
Quality documentation	Teamcenter can generate documentation as a by-product of the systems architecture and requirements capture processes. This enables product teams to produce documents of known quality with complete traceability. Teamcenter can trigger report generation when design-related events or API calls occur. Up-to-date requirements information can be incorporated into these reports in user-defined formats, including spreadsheet and document-specific formats. This capability is especially valuable for users who want to produce "live" spreadsheets for direct editing of the requirements database. Users can define the requirements-related information they want to generate into their documents, as well as produce these documents in any standard Microsoft format. They also can associate a format or template with a report and generate documents directly from the requirements database. These documents provide "live" windows into the database (i.e., changing the document also changes the source document in the database). Since documents can be emailed or posted, users who open these documents and change their content actually change the database.

Bringing systems engineering full circle. Siemens PLM Software believes that systems engineering is crucial to today's bottom line. For some time, product makers have been looking for a way to integrate "systems thinking" into the product lifecycle so that global product development and global manufacturing can be realized in real-world settings. Teamcenter solves this dilemma by integrating multiple systems engineering capabilities directly into its PLM foundation – providing product makers with a first-of-its-kind opportunity to perform systems engineering on a global basis.

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 4.6 million licensed seats and 51,000 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software's open enterprise solutions enable a world where organizations and their partners collaborate through Global Innovation Networks to deliver world-class products and services. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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