

Enabling innovation through systems
engineering and mechatronic product
lifecycle management

SIEMENS

White Paper

Manage the process of innovation for products that combine
mechanical, electronic, electrical and software technologies.

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Executive summary

Mechatronics, at the forefront of innovation

Innovative manufacturers across all industries have increasingly incorporated electronics and software into their mechanical products in order to deliver features that customers want at a competitive price. As competition has intensified and market windows have shortened, mechatronics technologies have become critical to success. Indeed, yesterday's mechatronic innovations are today's commodities.

Even as mechatronics have become more prevalent, most manufacturers lack expertise across all mechatronic disciplines including software, electronics and mechanical engineering. As a result, companies rely on partners to provide key elements in their products. This further complicates the primary challenge of mechatronic product development: integrating these disciplines into a coherent, synchronized product lifecycle.

According to AberdeenGroup, 68 percent of manufacturers cite synchronization of mechanical and electrical design representations as a key product development challenge. Forty-seven percent lack expertise in systems design or specific mechatronic disciplines. Yet, to be best-in-class, manufacturers must engage in a process of continual mechatronic innovation.¹

This same study found that manufacturers that are best-in-class in mechatronics product development hit their revenue, cost, launch date and quality targets 84 percent of the time. Four out of five of

these companies address mechatronic integration issues early in the design process.

Other important trends are affecting manufacturers' ability to optimize processes across the mechatronic product lifecycle:

- The development and manufacture of electronics components is increasingly outsourced to suppliers and strategic partners, increasing the challenge of coordinating development and protecting intellectual property (IP)
- Higher warranty issues can result from more complex products
- Security, configuration management and change management present significant challenges
- Complex mechatronic products increase the need for change control, version control and traceability

In order to compete, manufacturers need to be able to synchronize all aspects of complex product and process design, pushing all systems engineering and design issues to the front of the process whenever possible. They must optimize product performance, integration and quality by unifying interdependent mechanical, electrical and software subsystems – many of which may be designed and built by suppliers. According to Dr. M. K. Ramasubramanian, Associate Professor at North Carolina State's Department of Mechanical and Aerospace, this requires "the synergistic integration of precision mechanical engineering, electronic control and systems thinking in the design of intelligent products and processes."²

Product lifecycle management, or PLM, solutions can provide an ideal framework for implementing enterprise-wide mechatronics goals. When applied strategically, PLM technologies using extensible markup language (XML) and open system standards can create a digital environment that supports secured access and exchange of data among the multitude of applications that optimize and analyze the product and process functions in each of the disciplines and across all stages of the product lifecycle.

This paper discusses focus areas that need to be addressed if manufacturers want to create a highly efficient product development and manufacturing environment that fosters continuous and measurable mechatronic innovation:

Systems engineering and requirements management

Establish a framework to architect the mechatronic system, then create and communicate the system requirements to downstream decision makers.

Development management

Develop and synchronize all the designs, components and interfaces that comprise a mechatronics product in a whole system context.

Production management

Plan and develop the manufacturing processes for harnesses, printed circuit boards and software to track system configurations and quality.

Service and diagnostics management

Create a closed loop environment that ensures continuous improvement.

Systems engineering and requirements management

To respond to the challenges posed by mechatronic products, companies need to support new business practices that transcend disciplines and transform product development, manufacturing and support. They must address the complex integration issues that are driving up costs late in the design cycle and at all stages of the product lifecycle.

These issues are amplified when manufacturers work with partners and suppliers that provide needed expertise in electronics or software development. While this increases collective knowledge, it also adds complexity, as companies need to coordinate all stages of the lifecycle not only with other companies but also among multiple domains within each company.

To succeed, manufacturers need to implement a broad set of processes and methods for modeling and analyzing interactions among the requirements, subsystems, constraints and components that make up a mechatronics product. This requires a high degree of synchronization, optimization and cross-disciplinary management that is only possible through a systems engineering approach to managing the entire product lifecycle.

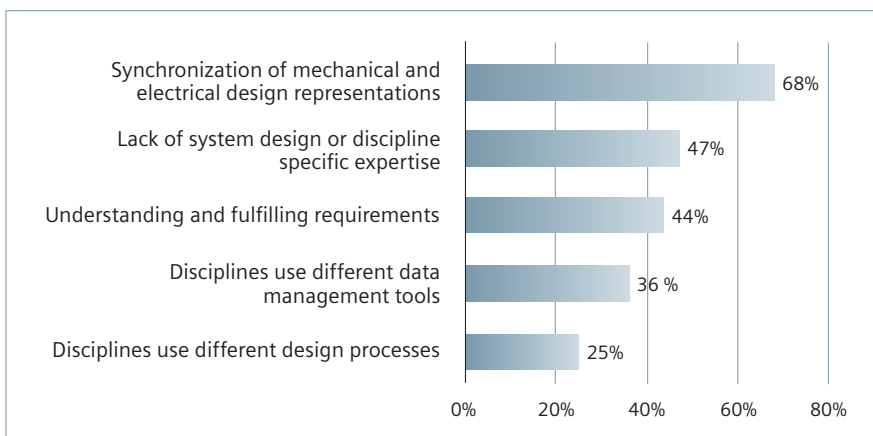
Systems engineering principles are fundamental to mechatronics product development. A systems engineering approach facilitates collaboration among multiple departments and disciplines – not simply within the enterprise but also among suppliers and strategic partners across the value chain.

When supported by enterprise PLM, systems engineering provides a holistic view of design, manufacturing and support that manages the complexity of dealing with multiple disciplines, design and manufacturing groups spread across the globe. It provides the ability to define, manage, control and synchronize all of the features and functions that comprise a mechatronics product, and to ensure they all interface seamlessly.

The various mechanical, electronic and software components that make up the final product must be aligned and evaluated as a whole in order to develop the optimal system architecture that meets performance and design requirements. All physical and functional subsystems and parts must work together as specified, and maintenance schedules have to be mapped out well in advance.

By subscribing to these criteria, subsystems can be designed to meet the needs of the overall product. Product-wide changes can be made in the system architecture by changing key product parameters such as the wing angle of an airplane or the table size, height and capacity of a machine tool. These changes can then be communicated through a formal change control and notification process. Along with the overall strength in large assembly modeling and inter-part modeling, digital product development is able to support the construction of complex, re-usable product assemblies.

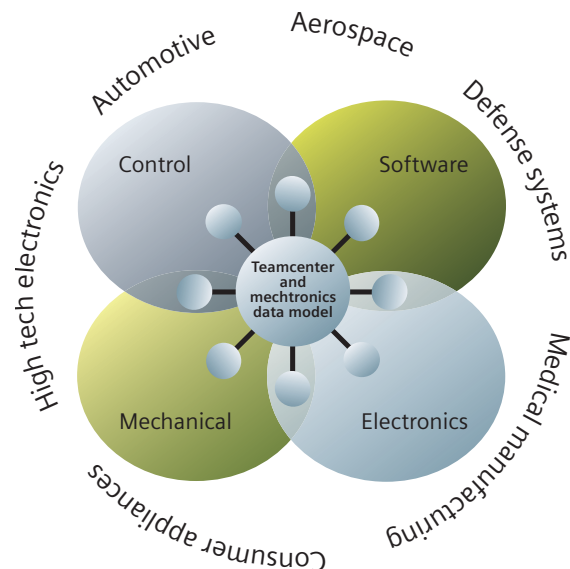
Mechatronic product development challenges¹



Designing products from the top down and independent of geometry accelerates the initial stages of product planning using information from prior designs. Systems-based modeling streamlines the initiation of new products by linking simplified conceptual models to the control structure. Changing product parameters in the control structure and propagating the changes through to the conceptual design allows users to quickly investigate design alternatives.

Essential steps for optimizing mechatronic product development

- Resolve design and integration issues as early as possible in the product development process by harmonizing mechanical, electrical, software engineering systems
- Improve collaboration by more tightly coordinating activities with strategic partners across multiple domains and disciplines
- Communicate complex product requirements among teams in suppliers and OEMs with as much system and engineering context as possible
- Provide all disciplines with ready access to synchronized product data
- Bridge separate IT environments for each engineering discipline



PLM solutions facilitate the development of mechatronic products by providing capabilities that can model and analyze interactions among the requirements, subsystems, constraints and components of complex products that can include mechanical, electrical and software elements. PLM enables engineers to rapidly model and evaluate design alternatives to ensure that products are right the first time. Real-time decision making takes place in the context of the initial design intent as well as real-world experience on the factory floor. Traceability is supported throughout the life of the product.

PLM provides a robust data management environment that enables companies to manage mechanical, software, electronic and electrical components both as individual elements of a product and as an integrated whole. By including electronics and embedded software in revision control, engineering workflows, change management and configuration management, the right data management solution can help companies optimize processes across multiple design and manufacturing disciplines throughout the product's life.

Requirements management

Early in the mechatronics development cycle, companies need to focus on defining customer needs and the functionality required for each product component or subsystem. Requirements are documented and preliminary designs are shared in a design synthesis process. Products and systems are then validated and modeled within the context of the whole product. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets user needs.

At the same time, market requirements must be supplemented with quantifiable constraints that determine the success of take-to-market programs in terms of their cost and delivery schedules, as well as their ability to satisfy established performance, ergonomic, safety, usability, reliability, maintainability, recycling/disposal and other compliance-related metrics.

Companies must leverage systems engineering to model and analyze the interactions among a product's requirements, subsystems, constraints and components and to optimize the tradeoffs that drive crucial decisions across the entire product lifecycle. The result of this systems architecting process is a correct set of product requirements that must be managed and closely integrated within and across disciplines to effectively feed product engineering and manufacturing.

Within an optimized mechatronics requirements management environment, product teams across multiple disciplines understand their decisions in the context of the whole system'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. This should include managing all relevant designs and variants, product specifications, models (including 3D simulations) and test results.

With this in place, requirements can directly influence the processes that cross-discipline teams employ when making and executing design decisions. Design teams 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.

Companies need PLM systems in place that can effectively support mechatronics requirements management. These systems must have the capability to manage change across multiple disciplines in real time. The best of these systems feature multi-discipline traceability capabilities to ensure proper document parsing and assembly. Such features can be used to create compliance documentation for the whole product across its lifecycle.

Development management

Mechatronics has become increasingly prevalent for the simple reason that developing new software is often much less expensive than providing the same feature in a mechanical form. Products will continue to evolve from simple mechanical systems to complex networks containing distributed computer nodes designed to deliver added features or value. If an assembly can be replaced with a software component, everything else being equal, the manufacturer is likely to opt to change the software component. In addition, software is easy to change and highly flexible.

The development of mechatronics products requires that companies excel not only in specific disciplines, but also in coordinating development efforts across disciplines and across organizational boundaries.

Manufacturers that are successful, however, can boost their innovation capacity through the integration of software that creates more distinctive products and enables product line extensions that directly lead to new revenue opportunities. They also can streamline costs by reducing the number of mechanical configurations that need to be supported as software takes over more of a product's mechanical characteristics.

Product development

Mechanical, electrical and software engineers have distinctly different design processes, organizations and technology. In the past, the very different product elements created by these diverse groups were integrated through a series of physical prototypes, a costly and time-consuming process of trial and error. By contrast, a systems-level approach to mechatronics product development provides all contributors across the product lifecycle with an understanding of the product as a whole. It enables them to use that total product understanding to better optimize the tradeoffs that drive detailed design, manufacturing, sourcing, sales and service decisions throughout the product lifecycle.

This integrated, iterative design process 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 execution.

Mechatronic products require companies to coordinate development within and across disciplines. For example, the increasing requirement for sophisticated control systems in products across a wide range of industries has created an explosion in the number of electrical control units (ECUs) needed to produce innovative new products. Indeed, the printed circuit board has significantly changed new product design. While often outsourced to third parties, the design of printed circuit boards (PCBs) remains a critical part of the process. Today, from the initial inception, to creation, to analysis, to manufacturing, companies need a comprehensive solution for PCB design and manufacturing that includes visualization tools that provide quick diagnostics and error tracking.

Seiko Epson corporation cuts micromechatronics development time by 50 percent

Seiko Epson is at the forefront of technological revolutions in the color imaging field, robotics, precision machinery and electronics. The company creates stylish, durable and accurate Seiko watches with tightly synchronized mechanical, electronic and software components. The company's constant focus on innovation and precision has enabled it to develop the world's most advanced micromechatronics capabilities (the synergistic integration of microelectromechanical systems, electronic technologies and precision mechatronics with high added value).

Since transforming from a slow, sequential process to a unified digital design and manufacturing environment supporting continuous innovation, the company has successfully transformed to a fully automated environment that validates products through virtual prototyping. Development times have been reduced by 50 percent and prototyping costs have been slashed in half. Quality metrics have shown 100 percent improvement.

Any change in the product may affect PCB requirements, such as power requirements or components chosen as well as the binary code specified by a second subsystem supplier. Software loaded on multiple control units in the system needs to be compatible, manufacturing needs to know which configurations work and if there is a field problem, the maintenance team needs to know about the as-built configuration to provide optimal support.

Similarly, companies need to synchronize the overall product development process with software source code, calibration and configuration parameters, build processes, and test structures as well as binary lifecycles governing embedded systems. Improved software lifecycle management enables companies to more accurately predict functional performance and to evaluate multiple product design alternatives more efficiently.

In the process, companies can gain important design insights and make smarter engineering decisions earlier in the design process – leading to the creation of high performance, high quality and more innovative products while reducing total product costs.

In many industries such as aerospace and defense, automotive and machinery, the harness lifecycle remains a critical process. A growing number of safety issues are driving the need for redundant systems that require early validation and analysis. This may include space allocation, power consumption analysis, network bandwidth and latency.

Effective harness lifecycle management requires improved integration among ECAD, MCAD and software applications to ensure synchronization of the product development effort, thereby speeding product development time and enhancing engineering productivity.

As design complexity increases, wire content grows as fast as software content. New communication buses are continually being added and power consumption is pushing the limits. To deal with these issues, a complete view of harness design is needed

in order to address space allocation early in the process. The early space allocation enables companies to re-use existing components from proven designs. The early space allocation also provides the link between the 2D and 3D design aspect. This iterative process is intermixed with circuit analysis.

PLM solutions with embedded software management capabilities can provide a synchronized view of software and electro-mechanical parts across the lifecycle. This view is based on the same packaging criteria that enable companies to significantly reduce design iterations resulting from versioning errors. Companies can prevalidate virtually everything well before the product reaches the make/deliver stage. With better control of the mechatronics product development process, companies can lower their expenses associated with regulatory compliance and reduce the need for costly and complex after-sale product software service updates. The improved product quality and cost reductions can translate into higher revenues and increased profit.

Agilent Technologies reduces time and cost with virtual prototypes

Agilent Technologies is a world leader in the manufacture of opto-electronic devices, including optical encoders used to measure velocity and location in motion control systems. Optical encoders are bonded to the carrier or substrate using a thermal process. An integrated digital design environment supporting mechatronics applications allows for highly effective virtual prototypes. Since it was not possible to attach a physical thermo-couple to the device interface, simulation was the only option to validate the design. The first simulated prototype passed reliability tests the first time. Reductions in time and cost of prototyping have made simulation the only option.

Process development

The process of incorporating electronics and software into traditional mechanical products is fraught with peril. Change in any one component may have ramifications across all other product components and systems. Consider the communication required to coordinate a length change of a wire in a harness, designed by a subsystem supplier. The change can affect a PCB's power requirements or the binary code specified by a second subsystem supplier. Software loaded on multiple control units in the system needs to be compatible. Manufacturing needs to know which configurations work and if there is a field problem. And the maintenance team needs to know about the as-built configuration to provide optimal support.

One of the greatest challenges of increased complexity is to determine whether to manufacture a unique harness for each product delivered or to trade-off manufacturing efficiency and extra content. Manufacturability needs to be validated as early as possible. Formboard tools provide the manufacturing view of the product so that companies can quickly build tools and jigs around the harness.

Failure to fully communicate the ramifications of change can have serious consequences. If a mechanical engineer fails to tell the appropriate engineer in electronics or software about the latest change, the electrical or software engineer might have conflicting requirements. In this case, each discipline's bill of material might be out of synch. Worst of all, all of the engineers involved might think that these issues are someone else's problem and therefore fail to take corrective action.

Ford achieves dramatic cost savings with embedded software

Ford Motor Company deploys an in-vehicle software data management solution on 57 worldwide vehicle programs, including the customer favorites Ford Explorer, Mustang and Escape Hybrid. The system supports synchronized mechatronics design that helps Ford track embedded software content associated with an electrical control unit (ECU). The solution enables Ford to leverage its global innovation network by tracking content throughout the lifecycle of a vehicle and coordinating its use and function as part of the overall system. In-vehicle software management capabilities enhance enterprise-wide collaboration and standardize product data management associated with the growing volume of embedded software that Ford is building into its fleet of increasingly intelligent vehicles.

Simulation and validation

Despite the steady advance of manufacturing automation, today few manufacturing companies have adequate tools to support the sophisticated levels of manufacturing testing and validation required for mechatronics products. 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 systems.

While simulation and validation might be optimized within specific development and process domains, today's mechatronic products require an integrated simulation model that can validate the whole product against requirements. Simulation models must connect with product functions as well as features so that manufacturers can validate that the whole product works as planned.

Ideally, every phase of the product lifecycle – from conception through ongoing maintenance – should be tested and prevalidated. Wherever possible the process should be mapped to, and part of, the wider product development process. The impact of design changes must be anticipated and, when appropriate, existing processes and machining operations should be re-used and applied to new products. Gathering all manufacturing processes together in a single systems engineering environment provides the framework – an integrated “product platform” – for continuous improvement.

PLM technologies enable companies to establish an integrated simulation environment for mechatronics products by providing a digital manufacturing framework that supports virtual prototyping, including interface prototyping, to ensure first time quality for the whole product. With PLM, companies are able to prevalidate product configurations and eliminate

physical prototypes with highly reliable virtual prototypes.

An integrated simulation environment can be leveraged for hardware and software-in-the-loop testing. This hybrid testing environment supports the validation of new concepts and innovations within existing architectures.

Through PLM, companies also gain the ability to trace requirements to the system design and to physical components not only to virtually test the impact of changes made in any one area on other domains, but also to ensure that any change is reflected across domains. This enables early identification of problems in specific product configurations as well as validation of electrical design and architecture and helping teams to better quarantine issues and manage risk.

In addition, PLM enables companies to bring entire product histories along the process, moving from view to view in a logical schematic or in 3D model mode. Functions can be represented physically in views that are relevant to individual users.

When building complex products containing multiple subsystems, companies must be able to validate the manufacturing feasibility of products from the very beginning of the process, with the assurance that each “system” can be made and delivered on time and on spec. To do this, they must synchronize product manufacturing and sourcing processes with the rest of product development to ensure flawless product launches and smooth ramp-up. This requires a systems engineering environment to ensure that products are built and delivered according to plan.

As a result, companies are able to optimize product performance, integration, quality and reliability through the visual analysis of interdependent mechanical, electrical and software subsystems, constraints and components.

Production management

Discrete development activities need to come together at the right time in order to avoid delays on the factory floor. The proper timing for the introduction of each component into the production process must be well understood, as changes to existing processes will need to be made.

Upfront assurance that the product can be manufactured and sourced is essential. Before companies even think about the make/deliver process, they must evaluate that they have at their disposal the appropriate assets and resources across the value chain. Prior to manufacturing, part or component manufacturing, assembly planning, plant design and production management need to be thoroughly assessed and outlined in detail. Design and production alternatives with accurate cost forecasts should also be part of the plan.

Companies must be able to simulate manufacturing and production processes to ensure high quality and smooth flow. Process validation is also important for product variants. Here existing manufacturing operations, processes and plants are re-applied to product derivatives. To ensure that the older processes are able to work on new designs, a high degree of dynamic validation is required, applied as automatically as possible in the process.

PLM provides a digital manufacturing environment that supports not only the early validation of manufacturability and the impact of change on workflows. It also enables companies to evaluate various manufacturing scenarios prior to any commitment to hard tooling. Advanced PLM solutions that support mechatronics give companies the tools to manage and synchronize the manufacture of various components that need to come together for the whole system, including such capabilities as PCB assembly and test, box build and embedded software management.

More importantly, an enterprise PLM environment based on a scalable, open architecture enables manufacturers to interact with their suppliers' databases and process management systems and capture updates on their production schedules, quality results and order status. As a result, manufacturers are better able to plan their own production schedules.

Finally, PLM captures as-built data from the factory floor and makes it available upstream to inform future systems architecting, design engineering and manufacturing engineering decisions. This capability enables companies to trace the root causes of noncompliant or failed components. It provides a feedback loop that is fundamental to improved service and maintenance, reducing warranty and repair costs and facilitating validation of regulatory requirements.

Perkins Engines' "virtual factory systems" link the factory to product planning and development

Perkins Engines manufacturing engineers model production facilities in detail for process optimization. These models enable them to create a virtual production line and manufacturing routing sequence. PLM systems support this "virtual factory" and allow multiple design teams to synchronize product development and validate factory-floor processes.

Visualizing the shop floor effectively links the factory into the product planning and development process, thus closing the loop between finished goods and product designers. Since every step of the manufacturing process is synchronized along the value chain, they have seen a three-fold increase in process planning capacity and significant value in terms of financial return and time saved.

Service and diagnostics management

In today's competitive environment, customer service remains an essential element of customer retention. When a customer experiences a problem, it is important to be able to fix it on the first service call. As products become increasingly complex, this becomes more difficult than ever. Repair and warranty costs can cut into the bottom line.

For example, the harness must be supported from a service standpoint. Diagnosing problems in a harness today is extremely difficult as the wires are covered with overstock and taped. Consequently, identifying the true path of the route is difficult. Harness visualization tools enable the wire harness to be seen wire by wire, facilitating quick traceability and analysis of potential failures as they are identified.

A comprehensive service strategy that leverages mechatronics uses software diagnostics to proactively identify potential failures and to alert both the

company and its customers. When this approach is not feasible, a development and manufacturing environment built on PLM can provide complete information about the product, its current state and the configuration of hardware and software. Feedback from the field can be used to investigate the root cause of performance problems and pinpoint those elements that need to be revised.

In addition, change management issues extend beyond product delivery. Software changes might occur after a product has been shipped – indeed, this is one of the advantages of mechatronics products. These changes must be tracked for future in-field updates and for feedback to product designers. Mechatronics solutions must be able to manage the changes made to each asset based on its configuration and usage patterns.

Conclusion

In order to compete in today's dynamic global markets, manufacturers in a variety of industries – including automotive, aerospace, defense, high tech, industrial machinery, medical instruments and consumer products – increasingly incorporate mechatronics into their products. According to research by AberdeenGroup, 40 percent of the best-in-class incorporate electronics and software into every one of their products.¹

To be best-in-class, manufacturers must engage in continual mechatronic innovation. This requires companies to transform their approach to systems design, development, manufacture and support. They must synchronize all aspects of the product lifecycle and provide a digital environment through which discrete disciplines involved in mechatronic product development and manufacture can collaborate and communicate in real time.

Mechatronics has greatly contributed to the complexity of designing, manufacturing, delivering and supporting innovative products. In many cases, the development of electronics and embedded software exceeds that of mechanical components. To fully address the challenges presented by mechatronics products, companies need to implement data management solutions that effectively manage the software, electrical and mechanical components of products and their related manufacturing parameters in tight synchronization.

A scalable, enterprise-grade PLM solution built on an open architecture provides the capability to integrate discipline-specific applications, data and processes

into a unified whole. It enables companies to effectively manage the broad set of processes and methods required to model and analyze interactions among the requirements, subsystems, constraints and components that make up today's complex products. As a result, companies improve each contributor's understanding of the product as a whole. This total product understanding can then be used to better optimize the tradeoffs that drive detailed design, manufacturing, sourcing, sales and service decisions throughout the product lifecycle.

To accelerate the process and ensure demand-driven innovation, leading companies must create a real-time, global, collaborative environment that spans organizational boundaries. With PLM, companies can lower costs associated with integration issues that arise late in the design cycle, causing production delays and delaying product launch. PLM enables manufacturers to realize higher revenues and increased profit through improved product quality and reduced costs.

An integrated approach enables companies to effectively address the key areas discussed in this paper:

- Systems engineering and requirements management
- Development management
- Production management
- Service and diagnostics management

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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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