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System Design: New Product Development for Mechatronics

January 2008

Executive Summary

Today's manufactures are dealing with a growing trend to blend mechanical, electro-mechanics, digital control systems, and electronic design elements into one integrated system. While developing these mechatronic products is simply a matter of responding to market demand, coordinating the disparate engineering disciplines on a single design presents a set of demanding challenges for manufacturers to overcome. How effectively companies are able to address these challenges carries with it a significant impact on a company's ability to meet key targets that drive product profitability.

Research Benchmark

Aberdeen's Research Benchmarks provide an in-depth and comprehensive look into process, procedure, methodologies, and technologies with best practice identification and actionable recommendations

Best-in-Class Performance

Aberdeen used five key product development performance criteria to distinguish Best-in-Class companies. These companies enjoy significant performance advantages over their competitors, including:

- The ability to meet quality targets on a 95% average, 12% more often than the Industry Average and 1.8-times as often as Laggards
- The ability to meet product launch dates on a 92% average, 21% more often than the Industry Average and 2.9-times as often as Laggard performers
- The ability to meet revenue targets on a 96% average, 25% more often than the Industry Average and nearly twice as often as Laggard organizations

Competitive Maturity Assessment

Survey results show that the firms enjoying Best-in-Class performance shared several common characteristics:

- 51% more likely than the Industry Average and 2.8-times more likely than Laggards to notify other disciplines of the change
- 2.1-times are likely as the Industry Average and 3.2-times as likely as Laggards to allocate design requirements to specific systems, subsystems, and components
- 5.3-times as likely as the Industry Average and 7.3-times as likely as Laggards to digitally validate system behavior with the simulation of integrated mechanical, electrical, and software components

"One mechatronic aspect of our products is the interface devices we design that receive the signals from the computer and then cause control valves to move. Over the last forty years, this has reduced the cost of our components by approximately 50% while reducing the size and weight by approximately 75%. We get better performance for less cost."

~ Staff Engineer, Aerospace Manufacturer

Required Actions

In addition to the specific recommendations in Chapter Three of this report, to achieve Best-in-Class performance, companies must:

- Overcome the lack of cross-functional knowledge by implementing processes such as regular cross-functional design reviews and promoting better communication with design change notifications

- Identify system level problems early in the design process by leveraging simulation to validate system behavior
- Ensure the final system meets all design requirements by managing requirements throughout the entire lifecycle of the design from the initial capturing of requirements, as the design develops, and at the final testing phase
- Accelerate the controls design with automated software generation tools and simulations

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Chapter One: Benchmarking the Best-in-Class

Mechatronic product development has added a new level of complexity to product development as companies strive to integrate mechanical, electrical, and software components into their products. Each of these design elements draw on an engineering discipline with unique knowledge bases, processes, and design tools. Bringing them all together into a single product is far from a simple task. While there is no simple approach to systems engineering (an interdisciplinary field focused on the intersection of all electrical, software, and mechanical design elements), there are steps that leading companies are taking to improve mechatronic product development with the resources they have on hand.

Fast Facts

- √ Best-in-Class performers meet quality targets on a 95% average, 12% more often than the Industry Average and 1.8-times as often as Laggards
- √ Best-in-Class performers meet product launch dates on a 92% average, 21% more often than the Industry Average and 2.9-times as often as Laggard performers

Business Context

Not surprisingly, the top pressure survey respondents indicate as driving their efforts to improve mechatronic product development is shortening product development schedules (Table 1). As products increasingly incorporate embedded software and electrical systems, improving mechatronic product development is about being able to pursue the concurrent development of different design elements rather than following a more serial approach.

The second highest pressure, increased customer demand for better performing products, suggests that mechatronic products are increasingly becoming a market requirement. As customers demand products with additional functionality or simply improved performance quality, enterprises attempt to respond with products incorporating software and electronic components. While bringing the disciplines involved in mechatronic development together is not easy, remaining competitive means manufacturers must find ways to improve.

Table 1: Top Five Pressures Driving Companies to Seek to Improve Mechatronic Product Development

Pressures	Response
Shorter product development schedules	69%
Increased customer demand for better performing products	44%
Reduced development budgets	25%
Accelerated product customization	20%
Increased requirements to incorporate electronics and software into product	16%

Source: Aberdeen Group, January 2008

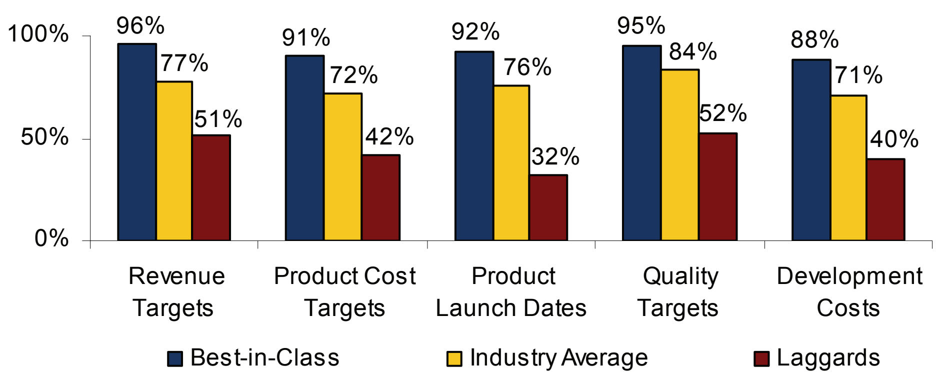
The Maturity Class Framework

Between December 2007 and January 2008, Aberdeen examined the mechatronic product development experiences of more than 140 enterprises. To uncover how companies successfully pursue mechatronic design, Aberdeen benchmarked the performance of survey respondents according to five key criteria which evaluated their ability to meet crucial product development targets, including:

- Product revenue targets
- Product cost targets
- Product launch dates
- Quality targets
- Development cost targets

Using these metrics, Aberdeen categorized respondents into the top 20% of performers (Best-in-Class), the middle 50% (Industry Average) and the bottom 30% (Laggard) of performers. Figure 1 highlights the considerable difference successful mechatronic product development can make to enterprise performance.

Figure 1: Best-in-Class Performers Meet Product Development Targets on an 88% or Better Average



Source: Aberdeen Group, January 2008

Challenges

Mechatronic product development is a difficult proposition: bring together three highly complicated disciplines with little understanding or visibility into their companion areas. Not surprisingly, companies indicate the top challenge of mechatronic product development is the lack of cross-functional knowledge or qualified systems engineers (Table 2). In particular, finding a solution for design conflicts (especially when they cross design disciplines) depends largely on the knowledge-base of the staff. While companies find it difficult to locate experienced systems engineers, they also do not have the design tools available that integrate the design data of all the elements that make up the product. Related is the inability to understand the impact a design change will have across disciplines, which is often a consequence of an engineer's lack of understanding of the other elements involved in the design as well as the lack of an integrated solution.

Table 2: Top Six Challenges of Mechatronic Product Development

Challenges	Response
Difficulty finding and hiring experienced system engineers / lack of cross-functional knowledge	50%
Early identification of system level problems	45%
Ensuring all design requirements are met in the final system	40%
Difficulty predicting / modeling system product behavior until physical prototypes exist	32%
Difficulty implementing an integrated product development solution for all disciplines involved in mechatronic product development	28%
Inability to understand the impact a design change will have across disciplines	18%

Source: Aberdeen Group, January 2008

While reported by half of all respondents, the Best-in-Class show as less likely to report a lack of cross-functional knowledge as an obstacle. Only 31% of these performers indicated as such. Rather, the Best-in-Class indicate a stronger focus on early identification of system level problems, which was reported by 54% of these performers and 45% of respondents overall. This also ties in with the difficulty of predicting / modeling system product behavior before physical prototypes exist (reported by 32% of all respondents).

The later in the design cycle a problem is identified, the less flexibility there is in finding a solution. Often, problems are not identified until a physical prototype is available. At this stage, there are limited options to make changes to the mechanical components and often the solution must rely on the controls side. In some cases, the options are so limited; the design requirements must be compromised to solve the problem.

The Best-in-Class PACE Model

Poorly managing the challenges of mechatronic product development can lead to considerable delays in product development. This ties in directly with the top pressure driving companies to improve the mechatronic design process. The Best-in-Class are able to manage the challenges of systems engineering by providing for a multidisciplinary approach, improving collaboration across disciplines, testing the performance of the entire system earlier in development stages through simulation, and formally tracking design requirements (Table 3).

Table 3: The Best-in-Class PACE Framework

Pressures	Actions	Capabilities	Enablers
▪ Shortened product development schedules	▪ Improve communication and collaboration across disciplines ▪ Increase visibility into the status of requirements ▪ Increase the ability to predict system behavior prior to testing	▪ Formal review process with all disciplines throughout design cycle and after components from each discipline are combined ▪ Design requirements across all disciplines are formally tracked and allocated to specific systems, subsystems, assemblies, and components ▪ System behavior is analyzed to determine function / architecture tradeoffs ▪ System simulations emulate the integrated electrical and software components to predict the behavior of the product ▪ Embedded software code is generated automatically based on software logic and the structure defined in the system model ▪ Controller behavior is validated by testing the embedded software code through physical hardware (hardware in the loop)	▪ Workflow tool ▪ Project collaboration tools ▪ Product data management (multi-disciplinary product structures / BOM) ▪ Design collaboration tools (visualization, review, markup) ▪ System engineering tools ▪ Integrated embedded software and control design tools ▪ Electronic Design Automation (EDA) ▪ Digital validation-system simulation of integrated mechanical, electrical, and software components ▪ Product data management (non-engineering data in product structure) ▪ Computer Aided Test (CAT)

Source: Aberdeen Group, January 2008

Best-in-Class Strategies

What manufacturers are doing to improve mechatronic product development is consistent with the overall knowledge obstacles that were indicated. The top action manufacturers report is improving communication and collaboration across disciplines (Table 4), cited by 71% of survey respondents. Improving communication across the design team makes sense for a multi-discipline approach, particularly when there are few engineers with a systems engineering background.

Table 4: Top Five Actions Taken to Improve Mechatronic Design

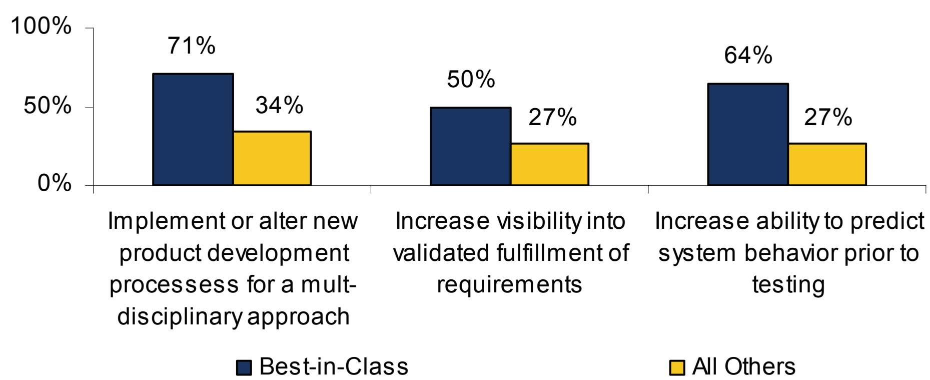
Actions	Response
Improve communication and collaboration across disciplines	71%
Increase visibility into status of requirements	49%
Increase ability to predict system behavior prior to testing	46%
Implement or alter new product development processes for a multi-disciplinary approach	43%
Increase real time visibility of product Bill of Materials (BOM) throughout the development process	39%

Source: Aberdeen Group, January 2008

The next area of focus is on the design itself, making sure the final system meets the design requirements. Companies are addressing this by increasing visibility into the status of requirements so that it will be easier to see which has been fulfilled.

Additionally, there are three areas where the Best-in-Class show a particularly differentiating focus on these actions (Figure 2). The first two of these actions (implementing and altering new product development processes for a multi-disciplinary approach and increasing the ability to predict system behavior prior to testing) correspond to the top actions indicated overall; but the Best-in-Class are even more likely to focus on these than any other group. However, the third area doesn't rate as a top action for all companies, demonstrating an extra step the Best-in-Class are taking. While a large number of companies are extending visibility into the status of requirements across disciplines, the Best-in-Class go beyond just increasing visibility to the status of requirements; they also increase visibility to which requirements have been validated. This demonstrates a greater attention to requirements among the Best-in-Class by managing, tracking, and validating them across the product lifecycle.

Figure 2: Strategic Actions of the Best-in-Class



Source: Aberdeen Group, January 2008

"We do a lot of cross-training to develop familiarity with both mechanical, electrical disciplines, and (on occasion) software disciplines. The impact on our design process has been the integration of development with manufacturing engineering. The benefits are: better first time results at all steps, fewer changes after manufacturing release, and the product gets out the door faster."

~ Senior VP Technical Services, Industrial Equipment Manufacturer

To predict system behavior prior to testing physical prototypes, companies are turning to simulation. Does the additional focus of identifying system level problems early by Best-in-Class companies really make a difference? By comparing the number of prototypes, costs, and timing, the conclusion is an obvious yes.

Table 5: Mean Prototype and Testing in Competitive Framework

Competitive Framework	Mean Number of Virtual Iterations	Mean Number of Physical Prototypes	Mean Rounds of Testing
Best-in-Class	25.3 iterations	5.8 prototypes	2.6 rounds
Industry Average	5.6 iterations	6.3 prototypes	2.9 rounds
Laggard	5.2 iterations	8.1 prototypes	6.3 rounds
Difference	**20.1 iterations**	**2.3 prototypes**	**3.7 rounds**

Source: Aberdeen Group, January 2008

Overall, the Best-in-Class are able to exchange more virtual iterations for fewer physical prototypes and rounds of testing. While this helps control costs, the ultimate goal remains saving time in the product development process to satisfy shrinking product development schedules. Based on benchmarked costs and time to build prototypes from the *Transition from 2D Drafting to 3D Modeling* (September 2006) and the *Simulation Driven Design* (October 2006) benchmark reports, the impact is significant. These results are further supported by companies developing mechatronic products (Table 6).

Table 6: Time and Costs Saved Based on Reduced Prototypes

Product Complexity	Number of Parts	Length of Development
Simple	Between 50 and 1,000	Between one month and less than one year
Moderate	Between 1,000 and 10,000	Between one and five years
High	Between 10,000 and 100,000	Between five and 20 years
Product Complexity	**Time to Build Prototype**	**Cost to Build Prototype**
Low	5.4 days	$2,503
Moderate	10 days	$36,558
High	17.3 days	$40,800
Product Complexity	**Time Saved by 2.3 Fewer Prototypes**	**Cost Saved by 2.3 Fewer Prototypes**
Low	12 days	$5,757
Moderate	23 days	$84,083
High	40 days	$93,840

Source: Aberdeen Group, January 2008

The 2.3 prototypes eliminated from the Best-in-Class process saves between 12 days and 40 days from the development schedule and between $5,757 and $93,840 from the development budget. These results directly contribute to the fact that the Best-in-Class hit their development costs, launch dates, and ultimately product revenues more frequently than the Industry Average and Laggards.

Aberdeen Insights — Strategy

Universities are starting to offer degrees in systems engineering, but it is not that widespread. Consequently, there are not a lot of systems engineers available with such degrees. Typically, systems engineers obtain their knowledge through years of experience, but finding people with this level of knowledge is not easy. It is not surprising that the top challenge of mechatronic development is finding experienced systems engineers.

continued

Aberdeen Insights — Strategy
An interesting finding is that Laggards and Industry Average companies are attempting to go outside of the enterprise to find these resources and are leveraging their partners. Industry Average and Laggard performers are four-times as likely as the Best-in-Class to indicate that they attempt to access partners with discipline expertise as a strategic action (28% and 31% of Industry Average and Laggards compared to 7% of the Best-in-Class). What this means is that Industry Average and Laggard performers are looking outside the enterprise, when it comes to coordinating mechatronic product development, the Best-in-Class have a greater focus on how to adapt to existing resources and leverage technology, altering the way product development takes place rather than simply adding designers. While these are also concerns for their competitors, the Best-in-Class focus on and enable visibility and coordination in a different way.

In the next chapter, we will see exactly what Best-in-Class performers are doing to make the most of their resources.

Chapter Two: Benchmarking Requirements for Success

Competitive Assessment

The aggregated performance of surveyed companies determined whether they ranked as Best-in-Class, Industry Average, or Laggard. In addition to having common performance levels, each class also shared characteristics in what they are doing to support the development of mechatronic products. Best-in-Class companies, in particular, have a wide range of capabilities in place to allow them to overcome the challenges of mechatronic development. At a high level, this comes down to how they coordinate design groups across engineering disciplines, manage design requirements throughout the development lifecycle, identify system level problems earlier, as well as design control systems.

Fast Facts

- √ The Best-in-Class are 2.1-times are likely as the Industry Average and 3.2-times as likely as Laggards to allocate design requirements to specific systems, subsystems, and components
- √ The Best-in-Class are 5.3-times as likely as the Industry Average and 7.3-times as likely as Laggards to digitally validate system behavior with the simulation of integrated mechanical, electrical, and software components

Case Study — Industrial Equipment Manufacturer

An Industrial Equipment (IE) manufacturer that is focused on developing high-volume, intelligent software-driven machinery, has been able to break down the silos of knowledge through cross-training. The Senior VP of Technical Services says, "I have done a lot of cross-training of my people to develop their skills in mechanical and electrical disciplines, and on occasion, in software as well."

These measures to support inter-disciplinary collaboration between teams have enabled both the design and manufacturing teams to have better insight into the downstream repercussions of design changes. As a result, the manufacturer has been able to get the product out the door faster.

In addition to overcoming the lack of systems knowledge, this manufacturer has also made strides in identifying system level problems earlier in the design process. The manufacturer validates control design using both simulations and actual hardware, in addition to the manual design walkthroughs. One of the things they have done is implement hardware-in-the-loop testing.

"Going to hardware-in-the-loop testing was a natural outgrowth of the concurrent development process and our efforts to model devices," he adds. "The ability to simulate the system and test software has greatly increased first time software quality and allowed the developers to have much more immediate and meaningful feedback."

As a result, the Senior VP says he has seen a range of benefits that include better first time results at all steps, fewer changes after manufacturing release, and faster time to market.

Coordinating Groups

The Best-in-Class have adapted their product development process in ways to overcome communication barriers and facilitate collaboration. By doing so, they have leveraged internal resources in a way that has allowed them to overcome a lack of system engineers and the problem of siloed knowledge issues that continue to challenge their competitors (Table 7).

Table 7: The Competitive Framework - Coordinating Disciplines

	Best-in-Class	Industry Average	Laggards
Process	Formal review process with all disciples throughout design cycle		
	100%	**67%**	**62%**
	Formal review process with all disciples after components from each discipline are combined		
	92%	**59%**	**54%**
	Cross-disciplinary integration issues are formally documented		
	100%	**48%**	**36%**
	Engineers are notified of changes to a subsystem in other disciplines that affect their designs		
	92%	**61%**	**33%**
Knowledge Management	Interfaces are configuration managed as a formal item in the product structure		
	75%	**29%**	**42%**
Performance Measurement	Design performance metrics measured across all disciplines		
	50%	**32%**	**14%**
Technology	Technology currently in use:		
	42% standalone workflow tool **96%** product data management (multi-disciplinary product structures / BOM) **83%** project collaboration tools **68%** design collaboration tools (visualization, review, markup)	**21%** standalone workflow tool **66%** product data management (multi-disciplinary product structures / BOM) **43%** project collaboration tools **52%** design collaboration tools (visualization, review, markup)	**25%** standalone workflow tool **53%** product data management (multi-disciplinary product structures / BOM) **46%** project collaboration tools **46%** design collaboration tools (visualization, review, markup)

Source: Aberdeen Group, January 2008

Design changes are inevitable throughout the course of product development. Market requirements vary. Customer needs shift. New regulations are passed. Technology evolves. Engineers find better ways of doing things, and design problems are identified. The impact of changes to a mechatronic system can have extensive consequences as a result of the interdependency between components. Design teams must be kept aware of how the changes between disciplines will impact their portion of the design.

The Best-in-Class address this issue by improving communication between different teams at work on a design. These performers show as 51% more likely than the Industry Average and 2.8-times as likely as Laggards to notify other disciplines of a change when it has a cross-discipline impact. They are additionally 2.1-times as likely as the Industry Average to formally document cross-discipline integration issues as they arise. Formal documentation provides greater visibility to design conflicts, improving communication among the team and making sure they receive appropriate attention.

"Our ultimate goal is to pull necessary functional groups together early in the development process. As of today, engineering is designing the product, with little interaction from other stakeholders. This should improve communication as well as the schedules to complete the projects."

~ Configuration Systems Manager, Electronic Security Manufacturer

Further, the Best-in-Class work to improve inter-discipline communication on a day-to-day operational level. These companies hold formal design reviews in order to coordinate design teams regularly throughout the design cycle as well as when design components of the system are brought together. This encourages visibility into the overall product design as the teams update each other, allowing them to flag and resolve potential problems as they occur. Ultimately, this allows teams to become more aware of how each portion of the design will impact one another.

The Best-in-Class enable this level of coordination through a range of tools designed to manage development processes and facilitate inter-discipline coordination. To begin, the Best-in-Class are twice as likely as the Industry Average to utilize workflow tools. These tools help to notify engineers when tasks need to be completed and regulate when tasks are handed off so that development processes can advance at a regular pace. The Best-in-Class also make use of collaboration tools to help teams come together even when separated by long distances. Finally, the Best-in-Class manage a multi-discipline Bill of Materials (BOM) within their Product Data Management (PDM) system so that all members of the design team can access it and see the parts that will affect their designs.

Managing Requirements Across the Design Lifecycle

In addition to finding ways to promote collaboration across disciplines, the Best-in-Class recognize that meeting design requirements is critical to arriving at the desired final product. In order to do so they plan the design at a system level and then tie these requirements to every aspect of the design. In practice, what this entails is not simply ensuring the requirements are right up front, but managing them throughout the entire design lifecycle (Table 8).

Table 8: The Competitive Framework - Tracking Requirements

	Best-in-Class	Average	Laggards
Process	Analyze system behavior to determine function / architecture tradeoffs		
	67%	**38%**	**29%**
	Impact analysis of changes to design requirements		
	71%	**43%**	**54%**
Organization	Dedicated role for gathering and managing requirements		
	100%	**48%**	**36%**
	Dedicated role for splitting product into specific systems, subsystems, assemblies, and components		
	77%	**32%**	**43%**
Knowledge Management	Allocate requirements to specific systems, subsystems, and components		
	100%	**47%**	**31%**
	Formally track requirement changes through configuration rules		
	75%	**50%**	**36%**
Technology	System engineering tools		
	50%	**35%**	**13%**

Source: Aberdeen Group, January 2008

Establishing Requirements from the Start

Knowing what you need to build is the first step to getting the final product right. The Best-in-Class focus on making sure that what needs to be built is fully defined before design work begins. Once these requirements are defined, the Best-in-Class plan for the system design upfront. Systems are complex, but with the planning done up front, some of this complexity is removed as it becomes clearer what is required of each portion of the design.

They are more likely to use specialized tools to do so, leveraging system engineering tools to capture requirements and model the system helps them plan the system out to make sure the requirements are met. Specifically, they are 74% more likely than the Industry Average to model the system with block diagrams and 91% more likely to then use the block diagram to capture and execute functional requirements. Doing so helps to keep the requirements tightly linked to the design ensuring that they are visible and easily referenced throughout the design lifecycle. Additionally, the Best-in-Class look at the system as a whole and are 76% more likely than the Industry Average to analyze system behavior to determine function / architecture tradeoffs.

"Our requirements management solution has provided us with a mechanism to easily define design criteria for each component, such as safety requirements. We also exchange information from customer and supplier databases in XRI format to review their differing requirement structures. This way the final system is aligned with the requirements."

~ Software Quality Manager
Automotive Manufacturer

Maintaining Dedicated Ownership

With three different disciplines working on the same product, it is easy for things to slip through the cracks. In order to compensate, Best-in-Class performers dedicate roles to requirement management and oversight. They are 72% more likely than the Industry Average to have a dedicated role for gathering and managing the requirements. This is just the beginning. The Best-in-Class are 2.4-times more likely to have a role dedicated to breaking the product into specific systems, subsystems, assemblies, and components and 2.1-times as likely to allocate requirements to the individual subsystems and components. This additional step is crucial. In fact, while Laggards show as more likely than the Industry Average to have a dedicated role to splitting up the design, they do not take the logical next step of allocating the requirements to them.

With ownership assured, the Best-in-Class revisit product requirements throughout the process. As design changes necessarily occur, they assess the impact to requirements. Specifically, they are 65% more likely than the Industry Average to perform an impact analysis of design changes and then track the consequences these changes bring to requirements through configuration rules. Interestingly, Laggards show as more likely to analyze the impact of a change to requirements than Industry Average. But, here as well, they don't follow through, lacking processes to communicate changes as well as the collaboration and system engineering tools to make sure the changes are effectively communicated.

Testing Early to Identify Problems at the System Level

As the design work proceeds, the Best-in-Class rely on simulations to help identify system level problems earlier. Simulation allows them to run virtual tests early in the design cycle. This means that problems can be identified and addressed before there are too many constraints on potential fixes. These organizations are 2.5-times as likely as the Industry Average and 3.9-times as likely as Laggards to run system level simulations that emulate the integrated electrical and software components in addition to the form and fit of the design.

Table 9: The Competitive Framework - Simulation

	Best-in-Class	Average	Laggards
Process	System simulations emulate the integrated electrical and software components to predict behavior of the product		
	58%	**23%**	**15%**
	Simulate the controller's behavior in its operating environment through the system model		
	62%	**36%**	**29%**
	Use test results to calibrate future simulations		
	54%	**29%**	**21%**
	Use simulations to determine where to place sensors		
	54%	**34%**	**15%**

	Best-in-Class	Average	Laggards
Technology	Integrated embedded software and control design tools:		
	▪ **58%** digital validation-system simulation of integrated mechanical, electrical, and software components ▪ **67%** product data management (non-engineering data in product structure) ▪ **69%** Computer Aided Test (CAT)	▪ **11%** digital validation-system simulation of integrated mechanical, electrical, and software components ▪ **32%** product data management (non-engineering data in product structure) ▪ **41%** Computer Aided Test (CAT)	▪ **8%** digital validation-system simulation of integrated mechanical, electrical, and software components ▪ **29%** product data management (non-engineering data in product structure) ▪ **29%** Computer Aided Test (CAT)

Source: Aberdeen Group, January 2008

These companies recognize that in order to be effective, testing and simulation must be a collaborative effort. As such, they promote collaboration between the test lab and the simulation group. To improve the accuracy of future simulations, these companies are 86% more likely to use actual test result data in simulation definition and then use simulations to determine where to place sensors – reducing the time required for tests.

Best-in-Class utilize a range of simulation and test tools. To begin, they are 5.3-times more likely than Industry Average and 7.3-times more likely than Laggards to use simulation tools to digitally validate the system level behavior. Next, they show as 68% more likely than the Industry Average to take advantage of Computer Aided Test (CAT) applications to support digital validation. Finally, to ensure that what is tested comes as close as possible to the end product, the Best-in-Class are 2.1-times as likely as the Industry Average to store non-engineering data in the product structure.

"We map out a system model which helps everyone see the big picture. However, because the controls design is necessary to run the system and tie all the parts together, we embed software implementation details within the system model. This makes it possible for everyone to see the requirements."

~ Chris Goldsmith, Director, Global Systems R&D, Brady Corporation

Rapid Controls Design

Mechanical and electrical products have been around for a long time. However, developing high performing mechanical products that can monitor inputs and react is a new trend. A critical component of these products is the controls design. This is an area where the Best-in-Class have implemented the capabilities that speed up design, addressing the top pressure driving improvements in mechatronic product design; shorter development cycles (Table 10).

Table 10: The Competitive Framework - Controls Design

	Best-in-Class	Average	Laggards
Process	Specify software implementation details within the system model such as the software design, processor, interface, standards, etc.		
	100%	**50%**	**69%**
	Generate embedded software code automatically based on software logic and structure defined in system model		
	50%	**25%**	**25%**
	Model system behavior with block diagrams		
	75%	**43%**	**43%**
Knowledge Management	Validate the controller's behavior by testing the embedded software code through physical hardware (hardware in the loop)		
	77%	**52%**	**50%**
Technology	Integrated embedded software and control design tools		
	64%	**41%**	**15%**
	Electronic Design Automation (EDA)		
	62%	**41%**	**9%**

Source: Aberdeen Group, January 2008

While requirements are managed at a high level, the Best-in-Class continue to ensure they trickle down to the lower levels of the design. These organizations are twice as likely as the Industry Average to specify software implementation details within the system model. This means time is not wasted hunting for the requirements. Speeding control design also extends to how the Best-in-Class write the code itself. To this end, the Best-in-Class are twice as likely to automatically generate code based on the logic and structure inherent in the system model which is much faster than manually writing the code. To support these efforts, the Best-in-Class are 51% more likely than the Industry Average and 6.9-times as likely as Laggard organizations to use Electronic Design Automation (EDA) to design the chips. Additionally, they are 56% more likely than the Industry Average and 4.3-times as likely as Laggard organizations to leverage integrated embedded software and control design tools.

Here again, the Best-in-Class show as more likely to leverage simulation to start testing before physical prototypes are built. This saves time and has the potential to avoid last minute debugging. As such, they are 48% more likely to use Hardware in the Loop (HIL) tests that validate the controller's behavior with the actual chip. This means they can learn if the chip works without waiting for the controller to be built.

"Going to HIL testing was a natural outgrowth of our concurrent development strategy and our efforts to model devices. The ability to simulate the system and test software has greatly increased first-time software quality and allowed developers to have much more immediate and meaningful feedback."

~ Senior VP Technical Services, Industrial Equipment Manufacturer

Aberdeen Insights — Technology

Increasingly, manufacturers are integrating mechanical, electrical, and software components into their products. While mechatronic products meet customer demand for better performing and smarter products, they introduce a whole new set of challenges. The many challenges manufactures face include figuring out how the components from different disciplines will actually work together.

Many manufacturers are turning to simulation solutions to address this challenge. Within the mechanical design environment, mechanical simulations can be run to virtually test the movement of the system to detect collisions or determine if the product will fail under a given load. However, this type of simulation focuses only on mechanical behavior. A growing trend in simulation is Hardware in the Loop (HIL). This type of simulation is especially helpful in mechatronic product development. HIL simulations "trick" the embedded software to think it is seeing real world inputs and outputs that would be coming from a sensor or actuator.

For example, in a simulation to test a new design for ABS breaks, a signal would indicate the tires were slipping as the breaks were applied. The controls would see this as a sensor reading and the proper response could be monitored. Simulations are run in real time, allowing manufacturers to not only verify proper functionality, but also ensure the response is timed correctly. To make the test even more realistic, HIL simulations run on the actual "hardware" or chip that will be installed in the final system. As with any simulation, manufacturers can run through a variety of scenarios and test cases far more extensively than may be possible with physical tests.

Chapter Three: Required Actions

Whether a company is trying to move its performance in mechatronic product development from Laggard to Industry Average, or Industry Average to Best-in-Class, the following actions will help spur the necessary performance improvements:

Laggard Steps to Success

- **Allocate design requirements to individual subsystems, subassemblies, and components.** Keeping track of requirements throughout a complex system is a challenge. By mapping requirements to the lower levels of the system, it is more clear what is expected from each component and the chance that the final product will meet the design requirements increases.
- **Facilitate communication and collaboration across the design teams.** With a team of varied skill sets working on a design, it is important that they are aware of changes that affect their design. Implement processes such as regular design reviews and investments in PLM technologies that include workflows, collaboration tools, and data management will help the team work together.
- **Leverage design tools that support the components of mechatronic products.** System engineering tools help to plan the system. EDA supports the chip design. Integrated embedded software and control design tools, as well as tools that generate embedded software code, help to accelerate the design of the controls system.

Industry Average Steps to Success

- **Identify system level problems early on with simulation tools.** There are a variety of simulation tools that allow the behavior of the mechatronic system to be validated prior to building a physical prototype. Not only does this save time and money, but virtual testing can be done earlier in the design cycle when there are more options to solve the problem.
- **Manage requirements throughout the design lifecycle.** Create a dedicated role for managing requirements. Map them to the individual subsystems and components and revisit them throughout the design process. Then during testing, validate the design against the requirements.
- **Overcome the knowledge silos and coordinate the team with process and PLM technologies.** Implement processes such a regular design reviews and formal documentation of integration issues to provide the team with better visibility to each other's

Fast Facts

√ Ensure the final system meets all design requirements by managing requirements throughout the entire lifecycle of the design from the initial capturing of requirements, as the design develops, and at the final testing phase

√ Overcome the lack of cross-functional knowledge by implementing processes such as regular cross-functional design reviews and promoting better communication with design change notifications work. Support the processes with PLM technologies such as collaboration tools, workflow, and data management.

Best-in-Class Steps to Success

- **Continue to leverage solutions to accelerate controls design.** Half of the Best-in-Class are automatically generating embedded software code based on software logic and structure defined in the system model. Leveraging this technology is not only faster than manually writing the code, it also reduces the risk of human error.
- **Continue to promote collaboration between the testing lab and simulation analysts.** By working together, these two groups are more empowered. Simulations are more accurate when they are based off of actual test data. Just a little over half of the Best-in-Class do this. Setting up for tests is faster when simulation data is used to determine the optimal place for sensors, but a little more than half of the Best-in-Class do this.
- **Continue to leverage PLM and system engineering tools.** The complexity of mechatronic systems requires a lot of planning up front and good collaboration between the engineering groups. PLM technologies and system engineering tools support this. Half of the Best-in-Class are using system engineering tools and less than half are using workflow tools which are typically included in PLM solutions.

Aberdeen Insights — Summary

To meet market demands, companies are incorporating electrical components and embedded software into their mechanical products. However, the process of developing mechatronic products is inherently challenging as components from three distinct engineering disciplines are integrated together into one system.

Aberdeen has identified four key capability themes required for Best-in-Class mechatronic product development. Best-in-Class performers put the processes and tools in place to coordinate the design team, manage design requirements throughout the design lifecycle, identify system level problems earlier, and accelerate the design of the controls. These core capabilities of mechatronic product development enable Best-in-Class companies to achieve top performance, specifically by helping them get better performing products to market sooner.

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Appendix A: Research Methodology

Between December 2007 and January 2008, Aberdeen examined how more than 160 enterprises develop mechatronic products. An online survey examined what is driving these enterprises to adopt global design strategies, the challenges they face, the actions they are taking, the capabilities they possess, and the technology they use. Aberdeen supplemented this online survey effort with interviews with select survey respondents, gathering additional information on design strategies, experiences, and results.

Responding enterprises included the following:

- *Job title:* Aberdeen's research sample included respondents with the following job titles: Senior Management (17%), Vice President or Director (18%), Manager (41%) and engineering staff or other (24%).
- *Department:* Survey respondents represented individuals in the following departments: manufacturing (16%), business process management (16%), engineering and others (69%).
- *Industry:* Respondents were drawn predominately from manufacturing industries. Automotive and industrial equipment manufactures each represented 23% of the sample, followed by aerospace and defense at 17%, high technology / software at 15%, computer equipment and peripherals at 12%, and consumer electronics at 10%. Other sectors included telecommunications, medical devices, and others.
- *Geography:* The majority of respondents (60%) were from North America. Remaining respondents were from the Asia / Pacific region (12%), Europe (23%), South America, Africa, or Middle East (5%).
- *Company size:* Thirty-four percent (34%) of respondents were from large enterprises (annual revenues above US $1 billion); 35% were from midsize enterprises (annual revenues between $50 million and $1 billion); and 31% of respondents were from small businesses (annual revenues of $50 million or less).
- *Headcount:* Twenty-three percent (23%) of respondents were from small enterprises (headcount between 1 and 100 employees); 28% were from midsize enterprises (headcount between 101 and 1000 employees); and 49% of respondents were from large businesses (headcount greater than 1,001 employees).

Solution providers recognized as sponsors were solicited after the fact and had no substantive influence on the direction of this report. By underwriting the distribution of this research, they have made it possible for Aberdeen Group to make these findings available to readers at no charge.

Study Focus

Responding product development professionals completed an online survey that included questions designed to determine the following:

√ What is driving companies to improve mechatronic product development

√ The challenges they face with mechatronic product development

√ The actions companies are taking to improve mechatronic product development

√ The capabilities and technology enablers they have in place to support their mechatronic product development

The study aimed to identify emerging best practices for mechatronic product development and to provide a framework by which readers could assess their own capabilities.

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Table 11: The PACE Framework Key

Overview
Aberdeen applies a methodology to benchmark research that evaluates the business pressures, actions, capabilities, and enablers (PACE) that indicate corporate behavior in specific business processes. These terms are defined as follows: **Pressures —** external forces that impact an organization's market position, competitiveness, or business operations (e.g., economic, political and regulatory, technology, changing customer preferences, competitive) **Actions —** the strategic approaches that an organization takes in response to industry pressures (e.g., align the corporate business model to leverage industry opportunities, such as product / service strategy, target markets, financial strategy, go-to-market, and sales strategy) **Capabilities —** the business process competencies required to execute corporate strategy (e.g., skilled people, brand, market positioning, viable products / services, ecosystem partners, financing) **Enablers —** the key functionality of technology solutions required to support the organization's enabling business practices (e.g., development platform, applications, network connectivity, user interface, training and support, partner interfaces, data cleansing, and management)

Source: Aberdeen Group, January 2008

Table 12: The Competitive Framework Key

Overview	
The Aberdeen Competitive Framework defines enterprises as falling into one of the following three levels of practices and performance: **Best-in-Class (20%) —** Practices that are the best currently being employed and are significantly superior to the Industry Average, and result in the top industry performance. **Industry Average (50%) —** Practices that represent the average or norm, and result in average industry performance. **Laggards (30%) —** Practices that are significantly behind the average of the industry, and result in below average performance.	In the following categories: **Process —** What is the scope of process standardization? What is the efficiency and effectiveness of this process? **Organization —** How is your company currently organized to manage and optimize this particular process? **Knowledge —** What visibility do you have into key data and intelligence required to manage this process? **Technology —** What level of automation have you used to support this process? How is this automation integrated and aligned? **Performance —** What do you measure? How frequently? What's your actual performance?

Source: Aberdeen Group, January 2008

Table 13: The Relationship Between PACE and the Competitive Framework

PACE and the Competitive Framework – How They Interact
Aberdeen research indicates that companies that identify the most influential pressures and take the most transformational and effective actions are most likely to achieve superior performance. The level of competitive performance that a company achieves is strongly determined by the PACE choices that they make and how well they execute those decisions.

Source: Aberdeen Group, January 2008

Appendix B:
Related Aberdeen Research

Related Aberdeen research that forms a companion or reference to this report include:

- *The Mechatronics Design Benchmark Report: Coordinating Engineering Disciplines*; August 2006
- *Engineering Change Management 2.0: Better Business Decisions from Intelligent Change Management;* September 2007
- *The Configuration Management Report: Formalizing and Extending CM to Drive Quality;* February 2007
- *Simulation Driven-Design Benchmark Report: Getting it Right the First Time* October 200
- *Transition from 2D Drafting to 3D Modeling* September 2006

Information on these and any other Aberdeen publications can be found at www.Aberdeen.com.

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