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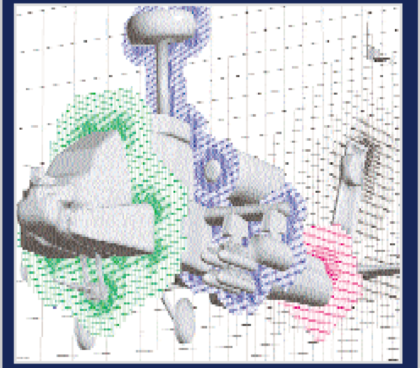

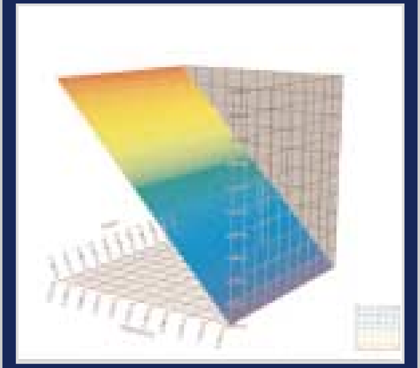

Leveraging Simulation:
The Design Innovation Process

Advanced analysis technology helps develop customer-focused designs that can differentiate a manufacturer from competitors and bring more revenue to the company's bottom line.

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The Design Innovation Process

In today's turbulent economy and brutal global markets, manufacturing companies are doing all they can to maintain their competitive edge by developing innovative designs. Products must stand apart from others, breaking new ground in performance, size, shape, capacity, durability, value or other attributes that compel consumers to select one product over another from a store shelf, or OEMs to do business with one supplier over another.

In many cases, companies use design innovation to improve on existing products. Other times they create a whole new class of products and dominate a market segment as competitors scramble to catch up. Automotive industry analysts note that Chrysler, for example, came out with the first minivan in 1983 and has never lost its market lead since introducing this innovative vehicle class.

In a world economy of radical change, product innovation has emerged as a key market differentiator across nearly all manufacturing industries and market sectors including automotive, aerospace, telecommunications, industrial machines, business equipment, discrete parts, and consumer products.

Strategies for Market Differentiation

"Past initiatives aimed solely at product cost, quality, or time-to-market are no longer sufficient to gain market advantage in today's highly competitive manufacturing markets. The focus today is on innovation: products that clearly differentiate themselves from others while also being affordable, reliable, and fast to market," explains Ed Miller, president of consulting and research firm CIMdata Inc. "To sustain sales growth and market position, manufacturers absolutely must have strategies for developing products to meet customer needs innovatively without driving up costs, sacrificing quality, or delaying product delivery."

Product innovation is playing a critical role in the automotive industry and gaining increasing attention as a strategic competitive advantage and overriding market issue by upper level automotive executives. "You ask me for volumes, products, sales, productivity. But nobody ever asks me for creativity, technology, innovation," says Jurgen Schrempp, Chairman of DaimlerChrysler. "That's where I make my money. The point is not to get three dollars out of the cost. The companies making the most money are the innovative ones, not the low cost ones."

In his book *Winning at New Products*, author Robert Cooper, professor of marketing at McMaster University and research fellow at Penn State University, contends that product innovation is vital to a company's success, prosperity, and even survival. "The annals of business history are replete with examples of companies that simply disappeared because they

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failed to innovate, failed to keep their product portfolio current and competitive, and were surpassed by more innovative competitors,” says Cooper, who notes that 40 percent of the major corporations in America during 1975 no longer exist today.

Voice of the Customer

Design innovation alone doesn’t guarantee market success, of course. Above all else, successful products are aimed at customer needs and expectations, according to Dr. Howard Crabb, president and CEO of consulting firm Interactive Computer Engineering. He authored the book *The Virtual Engineer: 21st Century Product Development*, and spent more than 30 years at Ford Motor Company, where he led initiatives to implement solid modeling and predictive engineering performed at the concept level of design.

“Stories abound about well-designed, reliable, and cost-effective products that flopped in the market because the public simply didn’t like them or failed to see a need for them,” explains Crabb. “Such products may have been designed using the most advanced technology and meticulously tested to meet strict functional and safety requirements, yet development took place with little or no input from the customer.”

With consumer tastes more discerning and their demands changing more rapidly than ever, Crabb contends that customers increasingly are now the focal point in product development, with this “voice of the customer” now a key element in the product development process. “In a globally competitive environment where one lost opportunity can sound the death knell for an entire company,” says Crabb, “Getting customer-focused, innovative designs to market fast is becoming an overriding determinant of whether a company thrives, survives, or dies.”

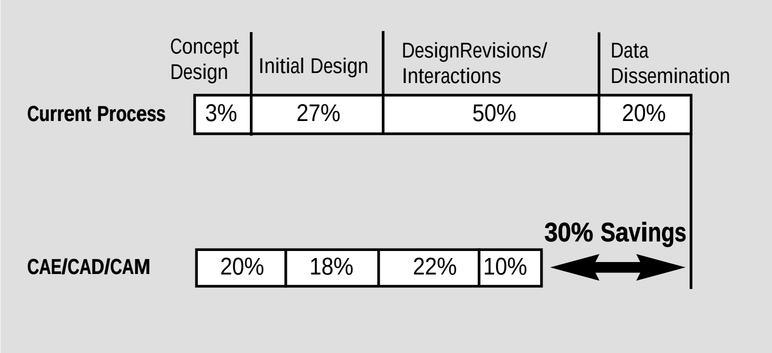
People, Process and Technology

Where do these innovative ideas for successful customer-focused products originate? Crabb notes that most manufacturers consistently launch innovative, winning products through a combination of people, process, and technology to translate a knowledge of customer requirements into viable products.

“Such a product development process depends on a familiarity with buyers and market trends combined with the latest technologies that can harness a company’s most critical asset – the expertise of its people,” explains Crabb. “In today’s competitive manufacturing markets, companies that want to stay in business absolutely must know their customers, develop ideas through sound engineering fundamentals, and rely on computer-based tools such as simulation technology to evaluate and refine designs as quickly and accurately as possible.”

Manufacturers today do indeed have a wide range of such simulation tools to deploy throughout the product development process. Some of the more powerful of these solutions include first-pass tools for performing analysis early in the design cycle, advanced optimization technology for refining product designs, and virtual prototyping methods for evaluating how products will perform in actual operating conditions.

Companies are finding that such tools can be used most effectively to facilitate design innovation if they are blended seamlessly within the product development cycle rather than used alongside the process. Simulation performed as an integral part of this process – rather than separately off to the side – continuously verifies the design and guides the configuration of the product.



“Until now, analysis has been done almost as an afterthought at many companies, performed apart from design and out of the product development loop,” notes Dr. James Crosheck, a retired structural engineer with Deere and Company and now head of the consulting firm Effective Engineering Solutions. “Advances in technology and processes notwithstanding, the single most important factor bringing simulation into the mainstream of product development is a radical shift in attitude. In engineering departments, simulation tools are now more commonly being regarded as an integral part of design instead of an outside service used only on a limited basis. And at the executive level, simulation is today being taken into account as part of corporate strategy in bringing more innovative products to market and more revenue to the company’s bottom line.”

First-Pass Tools for Front-End Analysis

First-pass analysis tools facilitate product innovation by enabling designers and engineers with a limited understanding of analysis technology to perform rough simulation early in the development cycle to evaluate concepts, conduct “what-if” studies, and compare alternative ideas.

Eaton's major criteria in the selection of DesignSpace for evaluation was the ability to efficiently and accurately import complex geometries, such as this clutch housing model from CAD packages.

Such tools overcome the limitations of traditional product development processes where engineers hand over design models and drawings to a central FEA group that must study and interpret the design, create simulation models from scratch, run the analysis, interpret results, and manually generate reports on the problem. The cumbersome process of exchanging information, building separate models, and manually recreating data often is slow and error-prone. Days or even weeks may go by before analysis results are available to designers, so simulation is often used mostly as a troubleshooting tool to hurriedly fix problems late in product development.

By performing their own analysis with first-pass tools, designers and engineers have more time to devote to creative aspects of the product design, and they have greater freedom to explore innovative ideas that otherwise would be bypassed in favor of more conservative configurations. In this way, first-pass tools are valuable in helping direct design in the early stages of product development when ideas are taking shape and innovative concepts can be investigated. Later in the cycle, specialized optimization routines can be used to refine designs, and more advanced simulations can be performed to study product behavior in greater detail.

This process of systematically testing ideas early in new product development is referred to as enlightened experimentation by Stefan Thomke, associate professor of technology and operations management at Harvard Business School and author of the Harvard Business Review article *Enlightened Experimentation: The New Imperative for Innovation*. According to Thomke, technologies - such as simulation - increase the number of breakthroughs by trying out a greater number of diverse ideas.

"Computer simulation doesn't simply replace physical prototypes as a cost-saving measure; it introduces an entirely different way of experimenting that invites innovation," explains Thomke. "The rapid feedback and the ability to see and manipulate high-quality computer images spur greater innovation: many design possibilities can be explored in real time yet virtually, in rapid iterations."

One of the original and more advanced first-pass tools for performing finite element analysis is the ANSYS DesignSpace software from ANSYS, Inc. Wizards guide users step-by-step in performing routine tasks for structural, thermal, dynamic, weight optimization, performance optimization, vibration mode, and safety factors. Design and analysis are tightly integrated through powerful bi-directional associativity that allows users to make design changes to their CAD model without having to re-apply any of the loads and or supports in DesignSpace, and conversely to automatically update CAD geometry from DesignSpace based on the simulation.

In the development of its single-person manned submersibles, Hawkes Ocean Technologies used DesignSpace in evaluating ideas for configuring the pressure hull pilot cockpit for the pilot. Previously, designers relied on basic hand calculations and added material to questionable areas of the structure. In attempting to evaluate conceptual ideas for new pressure hulls they had in mind for years, senior mechanical engineer Eric Hobson relates that "We could never get any meaningful results from hand calculations to make one design stand out from another. Using DesignSpace, we quickly drew up the conceptual designs and ran comparative analyses. It quickly became obvious which designs were good and which were not. Essentially, DesignSpace enabled us to take the design concepts we've played with for years and, in only a couple hours, decide which one to go with."

The benefits of front-end simulation also were shown in work at tier one automotive supplier Eaton Corp., where DesignSpace was used in a pilot program focused on designers performing first-pass analyses early in development. At Eaton's Design Innovation Center reports, the program demonstrated a 30% to 50% time reduction in the number of design iterations in evaluating products such as a clutch, for example. Efforts now are channeled toward the company's Six-Sigma program for design and development, where front-end simulation is assuming a critical role.

By providing rough "back-of-the-envelope" analyses, filtering out poor features before they become imbedded, and performing "what-if" studies,

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first-order tools such as DesignSpace keep the design headed in the right direction and serve as effective guides during the process. They help engineers determine which ideas are most promising and provide insight into why some are good or not. In this sense, the first-order simulation tool can be a valuable decision-support tool in helping guide the design process of developing innovative products in a timely and cost-effective manner.

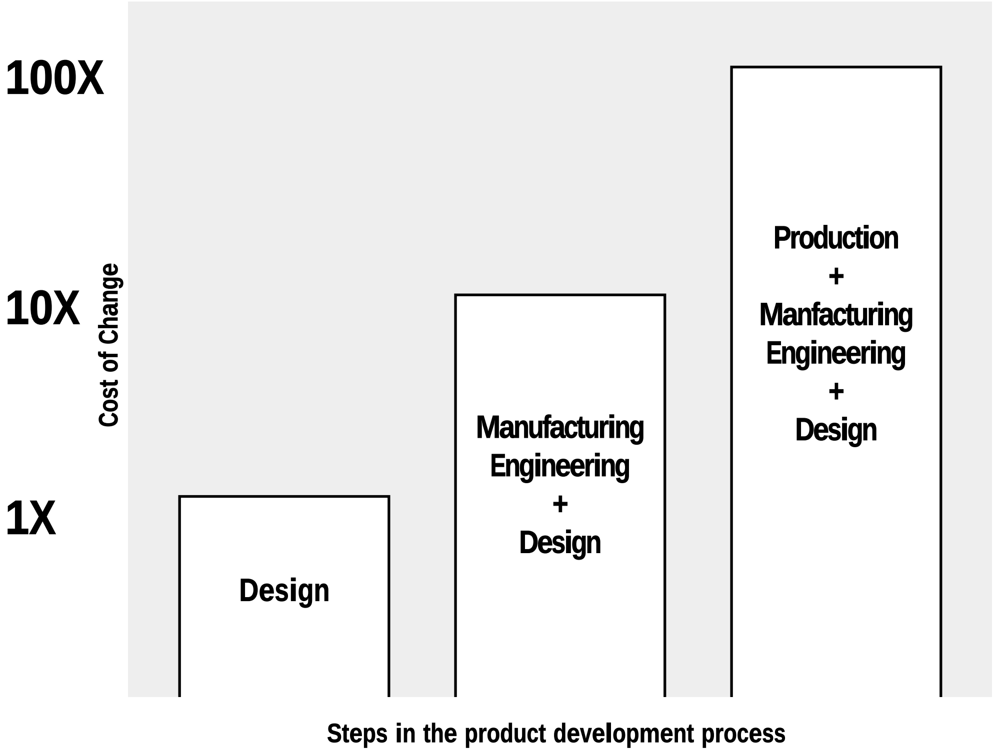
Optimization Technology Refines Designs

A major challenge in developing innovative designs is often the number and complexity of competing engineering requirements. Automotive components must be lightweight for the highest possible fuel economy yet strong enough for maximum crashworthiness, for example. And engine assemblies must be compact while maintaining adequate airflow for proper cooling. Many of today’s products involve a dozen or more such competing requirements. All are important, and neglecting just one can result in a missed opportunity in the market.

However fast single-solution simulation package operate, the tools are intended to generally handle only a limited number of variables simultaneously. Thus, users are faced with the tedious and time-consuming task of painstakingly running multiple simulations in attempting to iteratively zero in on an often-elusive good solution satisfying most of the requirements. More often than not, engineers develop a design based on only one of the most critical variables and neglect the rest, hoping any conflicts can be corrected later in the cycle. The result is usually not an overall optimal or innovative design but rather one that just works and barely performance and market requirements.

A variety of technologies are coming together in providing a new class of simulation tools that automatically optimizes designs based on boundary conditions and ranges of variables entered by the user. Design of experiments (DOE) technology performs numerous iterative simulations using various sampling and statistical methods, including probabilistic design and Monte Carlo simulation. Instead of performing multiple simulations, another approach called Variational Technology (VT) uses series expansion to make all necessary calculations much more efficiently using a single finite element solution. Depending on the problem, VT can arrive at solutions 10 to several thousand times faster than conventional DOE approaches.

Some of the more advanced design optimization software combines these technologies with CAE simulation methods and parametric CAD into an integrated solution. Such tools define the optimal dimensions of a part so that stress or weight is minimized, for example, or that a resonant frequency is below a certain level. The result can be a numerical listing of values for a recommended design, simulation response plots showing the



trends and influences of each set of variables, or an actual solid model of the optimal design as determined by the software. Also, users can make adjustments to any variable and see how these changes affect the optimized design. By clearly showing the relationship of multiple parameters and their effect on performance, design optimization guides the process of arriving at a configuration that might not otherwise have been considered with pure point-solution simulation.

In one of the first commercially available advanced solutions of this type, DesignXplorer from ANSYS, Inc. has a slider bar for each key variable provided for users to dynamically interact with the model, changing parameters and seeing how this affects the overall design. Feedback is immediate, so engineers can run through multiple "what-if" scenarios that otherwise would be too time consuming to perform with conventional tools.

In a goal-driven approach using this software, users can study, quantify, and graph various performance simulation responses as a function of design parameters for parts as well as assemblies. Bi-directional associativity with CAD packages allow designs generated through the system to be immediately translated into solid models, with the speed of performance simulation iterations matching the rapid pace of parametric CAD iterations. This speed saves time in arriving at optimal designs. Furthermore, the dynamic interactivity of the process provides users with greater insight into the problem and serves as a catalyst for exploring new ideas.

Companies implementing advanced optimization technology emphasize that the approach does not replace the creative aspects of engineering but rather augments the ability of engineers to develop innovative designs, essentially serving as a way to most effectively take advantage of the talent, expertise, and experience of a company's technical staff.

"Simulation-based design optimization can be used in automating routine, repetitive tasks in evaluating the influence of many different variables, leaving the engineer more time and energy to devote to the original, creative, and inspirational parts of the product development process," explains Gordon Willis, president of Vulcanworks Inc., an engineering consulting firm that has developed a proprietary system based on these concepts.

Their Advanced Engineering Environment uses the ANSYS Workbench Environment in tailoring the solution to the processes, product types, and design goals of each client. Vulcanworks consultants first work with clients in determining the key variables for the product, then extract the design rules governing each of these variables. The resulting knowledge base is linked to simulation packages that evaluate the product structure over a range of parameters, with the system often performing tens of thousands of DOE simulation iterations.

The final optimized design is displayed in the form of a 3-D parametric solid model generated by another automated link. Plots are also produced showing the sensitivity of the design to key variables. "Results often point to solutions which aren't intuitively obvious," explains Willis. "In this way, optimization technology augments engineering creativity and helps facilitate design innovation.

This approach has been used on a variety of automotive mechanical systems such as suspensions, engine components, steering assemblies, and body structures as well as non-automotive projects including fuel cells and marine applications. Willis cites benchmarks where this design synthesis process has compressed development time significantly. In the redesign of an automotive body structure to lengthen the wheelbase and raise occupant seating, for example, 720 person-days (12 people for 12 weeks) were required to complete the project compared to only six person-days (two people for three days) using automated design synthesis. Similarly, work on a suspension system that normally takes 60 person-days was done in only two person-days.

"One of the crucial parts of the whole process – and what takes the most time – is establishing clear design goals right from the beginning," explains Willis. "All the many design variables for individual components and assemblies cascade down from overall attributes that make the product unique, differentiate it from competitors, and motivate buyers to purchase it. Nailing down these key attributes early in the cycle is essential in developing an optimal design, not only from a strict engineering perspective but also from the standpoint of product innovation."

Simulating the Real World with Virtual Prototypes

Virtual prototyping simulates an entire system or subsystem in its operating environments to study and refine real-world product performance. These often are multiphysics analyses for studying the interaction of all factors encountered throughout the overall product during operation, including real-world factors that radically influence performance such as temperature, fluid flow, vibration, and fatigue, for example. Such simulation may determine the deformation of the body and wings as an aircraft lands on a runway, for example.

This approach overcomes the historic "build-test-redesign" problems by evaluating designs through computer simulation and analysis, earlier in the product development process and reducing reliance on validation testing late in the cycle. Often performance problems are encountered this late in the product development cycle necessitate repetitive redesign cycles until satisfactory performance is achieved, with several testing iter-

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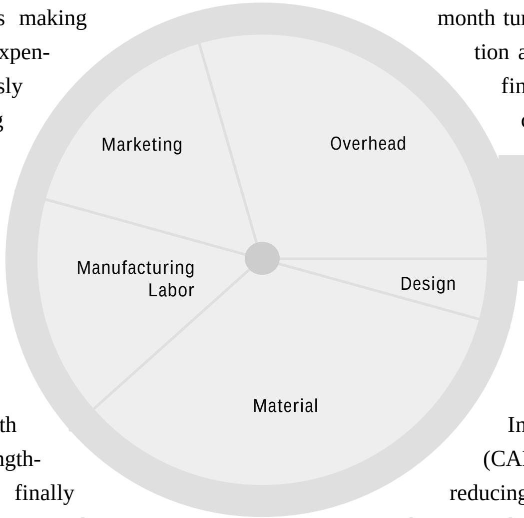
ations usually required. This adds considerable time and cost to the development cycle, with automobile mock-ups costing $300,000 to $500,000 each and requiring months to build, for example.

Studies have shown that the cost of change increases exponentially with each stage of development, thus making changes costly during detailed design, very expensive during prototype testing, and tremendously high during production. Moreover, correcting errors after the product is sold can be prohibitive in terms of recall and warranty costs, sometimes causing economically catastrophic consequences for manufacturers. Also, designs are often far less than optimal, with quick-fix changes to meet scheduling demands solving isolated problems by usually detracting from the overall design. Components may be grossly over designed with needless weight and bulk, for example, to strengthen failed assemblies. When the product is finally launched, the window of market opportunity may have closed, or performance may not satisfy customer demands and expectations.



Product design can be as low as 5 percent of total product cost.

By using simulation as part of the design process in the early stages of product development when concepts are just starting to take shape, engineers avoid such difficulties later in the cycle by exploring various product configurations, evaluating different part geometries and materials, and examining all the many tradeoffs inherent to product development.

The aim in virtual prototyping is not to entirely eliminate physical testing but rather to use a simulation-driven product development approach to guide the design and reduce the dependency on physical testing for troubleshooting problems late in development. This approach leads to fewer, but better, hardware prototypes that serve to verify a refined design at greater levels of sophistication. This can result in significant time reductions, cost savings, quality improvement, and product design innovation.

By shortening the cycle needed for physical testing near the end of design, virtual prototyping gives engineers added time earlier in development to explore and investigate innovative concepts. Moreover, identifying and correcting problems through virtual prototyping before designs are committed to hardware ensure these design innovations are carried through in the final product configuration. Otherwise, companies would tend to stick with familiar approaches rather than risk encountering unforeseen problems with new and untried product configurations and manufacturing processes.

Automotive companies take the lead in the use of virtual prototyping, which OEMs and suppliers are leveraging in the industry's drive to compress vehicle development time. Average cycle time was 48 to 60 months in the 1990s and is currently around 24 to 36 months, with some automakers shortening the process to only 18 months and aiming for a 12-month turnaround. This often involves multi-physics simulation and a combination of analysis technologies such as finite-element analysis, multi-body dynamics, and computational fluid dynamics.

According to Dr. David Cole, President of the Center for Automotive Research at the Altarum Institute, the use of computer-aided engineering (CAE) and virtual prototyping technology is critical in reducing reliance on physical prototypes, reducing cost and shortening the overall product development process.

"The use of analytical methods more than doubling over the next five years will likely translate into significant savings for automotive manufacturers and their suppliers," says Cole. He cites one manufacturer that cut product development time and cost significantly by reducing the number of physical prototypes by nearly 50 percent. The goal of these efforts in the automotive industry is to shorten the time to market, or more precisely, compressing the time to innovation. That is, the duration from the early conceptual stages of development until production begins. Cole explains that "The key to this level of product development time reduction is math-based engineering – the world of virtual prototyping using modeling, analysis, and simulation."

Virtual prototyping approaches are being implemented widely across the broad range of manufacturing industries to reduce the reliance on physical testing. Using simulation, Baker Atlas was able to significantly eliminate unnecessary hardware prototypes in the design of a new leak proof elastomer seal for oil-well drilling instruments, for example. The units must withstand the environment of deep wells five miles down, where pressures exceed 25,000 psi and temperatures reach 400° F.

According to Eyad Ammari, a Baker Atlas mechanical engineering analysis tasked with developing the seal, designs for several prototype seals of different shapes and sizes would ordinarily have been molded and tested, with each iteration taking at least six weeks. Using ANSYS Mechanical software to perform nonlinear hyperelastic analysis, five seal designs were studied and the best one selected. If those prototypes had been physically produced, the molding and manufacturing costs alone, just on one project, "would have been tremendous," Ammari explains. "More importantly, we got all this work done in about a month, including the time needed to do reports and the usual exchange of information and change of design requirements. Using ANSYS analytical software was considerably faster."

Virtual prototyping is playing a key role in the electronics industry, particularly in developing packaging configurations for semiconductor devices. Semiconductors in compact enclosures must resist damaging heat build-up while withstanding an array of structural loads with wide ambient temperature swings. Specific types of analyses performed with the software in the development of hybrid power modules at Motorola include: thermal studies on steady and un-steady (transient) heat dissipation, coupled field analysis (thermal/electric) to balance voltage drop and temperature, time-independent plasticity analysis to determine optimum lead forming geometry, viscoplastic analysis to study fatigue in soldered joints, linear elastic stress analysis to determine effects of applied loads, and dynamic analysis to determine natural frequencies and normal modes of vibration.

Engineers also use magnetic analysis to determine transient capacitance and inductance of components. In one project at Motorola, distortion of solder joints was quickly determined with a single ANSYS viscoplastic analysis run. This represented a huge time and costs savings and not only lead to better solder reliability but also an improved manufacturing process. Ordinarily, making such a determination would require building and testing a set of physical prototypes: a process that generally takes over four months and costs nearly $250,000 for tooling and manufacturing.

Virtual prototyping is an indispensable tool in the development of micro electro mechanical systems (MEMS). Made with semiconductor construction techniques, these devices have tiny parts measured in microns (millionths of a meter) frequently combined with integrated circuits on a single chip to provide built-in intelligence and signal processing. These small, intricate devices must perform accurately and reliably, often in the hostile environments of vehicles and industrial machines. The devices are used in a wide range of diverse applications including airbag deployment and manifold pressure sensors in automobiles, disposable blood pressure sensors, ink-jet printer nozzles, pacemakers, and industrial equipment monitoring systems.

Engineers developing MEMS rely on simulation software to study these microstructures in determining stress, deformation, resonance, temperature distribution, electromagnetic interference, and electrical properties. Because many of these effects are interdependent, predicting output and performance of MEMS devices is generally a complex problem that often defies intuitive approaches used in developing larger assemblies. Whereas physical mock-ups of conventional electromechanical devices may undergo several test and re-design cycles where parts are modified and switched around, the initial semiconductor fabrication set-up for MEMS is so time-intensive that prototype testing is almost always done to verify the design rather than find bugs in it. "The device has to work right the first time," explains a design engineering manager at a major MEMs development company. "The design has to be refined up-front in development so the unit operates as intended when we validate with a single round of physical testing."

Implementing Simulation Tools

Because of differences in product strategies and corporate priorities, the simulation technologies best suited for a company's applications and the way these tools are utilized in the enterprise's product development process are unique for each organization.

Companies seeking to implement simulation - or to more closely integrate simulation into design processes - most always undergo a self-assessment of how products are currently developed, where improvements are possible, and what role simulation should play in new ways of operating. In some cases, companies already have experience in simulation and find it necessary to expand the use of thee tools or shift the manner in which they are utilized. Other firms not currently using simulation initiate programs to investigate the ways they might benefit from the technology.

Most often, the cost of implementing simulation software is justified based on return-on-investment from savings in expense reduction and operational efficiency. Such time and cost benefits are most easily quantified and extremely important for a company to determine. From a broader perspective, however, the greatest value of simulation for manufacturing companies is in facilitating innovation. Senior executives know that innovation in product development as well as manufacturing processes is key to a company's long-term potential in the market. In this respect, engineering simulation has been elevated from that of an obscure technology understood only by dedicated analysis to a critical component of a company's corporate market strategy.

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