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Tech-Clarity Insight:

The Five Dimensions of Product Complexity

Managing Complexity across the Product Lifecycle

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Executive Overview

The simple reality is that today's products are complex. They are complex to design, complex to produce, and complex to support. Across the manufacturing industries, the trend over the last ten years has been increased complexity. This challenge, whether it is inherent to the product itself or the difficult manufacturing landscape of the twenty-first century, has made the job of developing and delivering profitable products more difficult. One company facing increased complexity is Mercury Marine, a leading manufacturer of recreational marine propulsion engines. As Fred Bellio, Director or Processes, Systems and Global R&D for Mercury Marine explains, "*People don't recognize how much impact product complexity has on their cost and their business.*"

Effectively managing product complexity, in all of its forms, is an important business issue. This report examines how manufacturers address the five critical dimensions of product complexity to achieve maximum profitability, including:

- Mechanical Complexity
- Mechatronics
- Global Markets
- Global Design and Manufacturing
- Lifecycle Profitability

This report describes how PLM solutions help manage these five dimensions of product complexity on an enterprise scale, resulting in greater efficiency and better products.

Then, this report describes how PLM (Product Lifecycle Management) solutions help manage these five dimensions of product complexity on an enterprise scale, resulting in greater efficiency and better products. PLM was originally developed to manage complexity by improving processes such as change and configuration management, key tools for combating product complexity. As product complexity has increased, PLM has evolved, expanding to manage more aspects of product development, including a richer view of the product, more people involved in product innovation, more phases of the product lifecycle, and enabling more product-related processes. These capabilities make PLM the right tool to manage product complexity and enhance product profitability.

The Curse of Complexity

Products have become more complex mechanically, but companies have also moved to smarter products that include mechanical, electrical, and software elements. At the same time, expectations for new product development and engineering have grown even higher. Customers demand more innovation, and design lifecycles have shrunk

dramatically. Further complicating things, quality expectations have risen despite increased product complexity.

In addition to product complexity, markets have globalized and become more complex. As if that wasn't enough, companies themselves have grown more complex, as have their design and product development environments. In addition to these challenges, manufacturers need to focus on more than just the best product. Today, they must also address total lifecycle profitability by optimizing products for manufacturing and service, driving additional complexity. "*Complexity is not just a design issue,*" explains Mr. Bellio. "*It is connected from portfolio and product planning all the way through to manufacturing and service.*" Complexity is an issue throughout the product lifecycle.

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Compliance mandates also add complexity. Challenges like environmental compliance regulations that require engineers to minimize environmental impact and enhance sustainability of products, or compliance regulations that demand product traceability and genealogy, result in additional complexity. "*We live in an environment where so many products are certified, we have to keep things under change control and configuration management,"* explains Rick Kennedy, Senior Technical Manager of Electrical Systems Engineering for Honeywell. *"It is just the way we have to do business.*" This is the story for most manufacturers, the complexity can't be avoided – it is the direct result of today's manufacturing reality and must be addressed. And lean organizations mean that it must be managed effectively and efficiently.

1st Dimension: Mechanics

Even "simple" mechanical products have gotten more complex. Engineering advances have allowed engineers to design more functional products, and make them smaller and less expensive. By employing better design and validation tools, designers have been able to push the envelope to create products that were previously unachievable. The incorporation of new materials such as composites and nano-materials allows greater flexibility and innovation, but in return creates its own challenges.

In addition to the products, advanced design techniques to promote reuse and agility have also made things more difficult. Many manufacturers have moved to platform-based design, where products leverage a common base or "platform" that is the core on which multiple products will be built. In the same way, leading manufacturers are also employing modular design techniques that include independent subsystems that can be

interchanged to meet specific needs, with associated interfaces between modules defined and managed in order to facilitate incorporation of these "modules" into multiple products. While Mr. Kennedy explains that Honeywell has been dealing with complexity for years, he admits that "*Modularization and reuse is a newer concept in this industry. It is certainly a product complexity issue to keep track of everything.*"

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Mercury Marine also faces challenges due to platform and modular design. "*We see increased complexity based on the number of platforms we support,*" explains Mercury Marine's Bellio. In some ways these design approaches reduce complexity because it improves reuse of design and parts, but it also adds complexity to design and configuration management processes. Cost savings justify it, as does the ability to quickly introduce new technology or changes across a family of products. But it creates new challenges for engineers that must manage platforms and modules that must work effectively in multiple product scenarios.

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A related challenge is the increase in "mass customized" or tailored products. Many manufacturers have introduced configurability into their products, requiring final engineering based on order specifications. Even standard, pre-defined product variants that offer multiple options to customers require more engineering rigor and control. But as Mr. Bellio of Mercury Marine explains, "*We just don't have a choice – one size does not fit all.*"

2nd Dimension: Mechatronics

Beyond mechanical complexity, manufacturers have begun developing "smarter" products. Everything from airplanes to household appliances have evolved to include electronics and electronic controls. For example, modern automobiles may have 50 or more microprocessors managing everything from braking, to engine timing, to entertainment. This combination of mechanical, electrical, and software components, known as "mechatronics," has made products exponentially more complex. The complexity can even go beyond the product itself, as some products, like cell phones and navigation systems, may be parts of larger systems with additional applications on the device and servers, expanding the complexity to networking and operating systems.

For these products, all of the elements must be designed individually. But each of the design disciplines must work together, because all of the elements must be designed as a part of a system, and must be kept in sync. Keeping designs in sync is a basic challenge. More advanced companies are going even further by using simulation to validate products at a systems level as well as individual disciplines like mechanics.

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For some, this shift towards mechatronic products is relatively new. "*The mechanical side includes engines and drives, and now takes about 60% of our engineering effort, software controls for the engine and boat are around 25%, and electrical design like wire harnessing and electronic control units consumes 15% of our people's time,*" explains Mr. Bellio of Mercury Marine. "*To put that in perspective, software and electronics were maybe 5% just five years ago, and didn't even exist ten years ago.*" For others like Honeywell, mechatronics has been a way of life for some time. "*We have been doing it for a long time,*" explains Mr. Kennedy, "*Jet engines require electronic controllers, and most other mechanical components require electronics.*" Mechatronics have become the new standard for many industries, adding complexity. As Honeywell's Kennedy quips, "*I said it is not new, I didn't say it was easy.*"

3rd Dimension: Global Markets

Not all of the complexity in product development and engineering comes from the products themselves. Globalization has also complicated new product development. Today, manufacturers compete in global markets. This has brought about cost pressure, but also opened up new market opportunities. In this global realm, manufacturers compete for time to market on a global basis. Instead of introducing a product in one market and then localizing at a later time, leading companies are introducing products in multiple markets simultaneously or in rapid succession.

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Global product launches are challenging, because "one size does not fit all" in this area either. "*Localization in multiple geographies is also a problem,*" explains Mercury Marine's Bellio. "*Each market has a different set of criteria.*" These requirements might be based on local preferences, but may also be driven by local regulations. Understanding these requirements in advance helps companies optimize the number of product variants

required to meet multiple markets, and allows them to take a platform approach. But it adds yet another layer of complexity.

Beyond product development, globalization impacts the entire product lifecycle. "*As we transitioned from a North American player to a world player, usability and serviceability have become big issues,*" comments Mr. Bellio of Mercury Marine. "*On one hand globalization helped in market share and units, but it increased the complexity because we have to design the product to be serviced anywhere in the world by whatever local resources are available.*" Again, serving a global market offers significant business advantage, but comes with additional challenges.

4th Dimension: Global Design and Manufacturing

Globalization has not only impacted manufacturers' products, but the manufacturers themselves. Many manufacturers are now designing products globally. Where in the past product development teams were likely to be in one site, today they are frequently spread across the globe and often include other companies. "*Engineering went from site-based to functionally based,*" explained Honeywell's Kennedy. "*Global or not, it turned the whole engineering community into a much more virtual organization.*" Global design approaches and centers of excellence are valuable approaches, but keeping these disparate teams aligned and synchronized certainly requires additional effort.

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Globalization impacts design, but also production. As manufacturers have adopted increasing global supply chains to take advantage of local talent and cost benefits, product designers and manufacturers frequently find themselves crossing corporate boundaries in addition to physical ones. This has many companies adopting concurrent engineering strategies, and a "design anywhere – build anywhere" approach. "*We no longer design and build all of the subsections ourselves,*" describes Mercury Marine's Bellio. "*We now have partners to deal with that need to be integrated into the design process, and we are designing it all concurrently.*" Global manufacturing helps with localization, time to market, and cost objectives, but again bring about the need for additional control and communication.

5th Dimension: Lifecycle Profitability

While much of the complexity discussed to this point impacts design, companies also have to focus further into the product lifecycle. The disconnected processes and "throw it over the wall" mentality is giving way to more collaborative approaches, as we have discussed in regards to global design, manufacturing, and service. The later stages of the lifecycle are critical to the total profitability of a product across its lifecycle, and require more involvement from downstream resources. "*Different organizational groups need to be able to share information in a quick enough pace and in a complete enough way,*" points out Rick Kennedy of Honeywell. "*Product information must be available to people to make higher fidelity design decisions sooner. Otherwise, it can cause issues with suboptimal design, or significant rework.*" Today's competitive markets are not forgiving of manufacturing errors and high manufacturing costs. But production is complicated, as Mercury Marine's Fred Bellio explains. "*Product complexity in design is a challenge, but multiply that by ten for a production facility.*"

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Manufacturers have also taken on a greater role in service, Tech-Clarity's *The Service Lifecycle Management Approach* reported. In some cases, this increased involvement in service is to pursue higher margins from service work as globalization has driven product prices down. In other cases, customers are demanding that manufacturers take a more active role in the operation and service lifecycle through tougher service level agreements (SLAs), performance-based contracts, or by paying for the product as a service as opposed to an asset.

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Even in more consumer-oriented industries, market demands have shifted to demand increased accountability by the manufacturer, as warranty periods have increased. "*Our product liability and warranty period has expanded,*" Mercury Marine's Bellio explains. "*It has gone from one year to three, and now to five years.*" This increased expectation places additional burden on manufacturers. Globalization has also made an impact here, as manufacturers are now supporting products in very different environments with different expectations and even in different languages.

Managing the Complexity - PLM

PLM was designed to manage the complexities inherent to engineering and product development. Two of the critical challenges in designing and manufacturing quality products are change and configuration management. With the complexity of today's products, including configured items with multiple variants and platform-based designs, manufacturers can't afford manual processes or defining their products via spreadsheets. "*Without solid change management, quit now,*" jokes Mr. Bellio from Mercury Marine, "*You have to have good change and configuration management processes, they play hand in hand.*"

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PLM helps manage product information throughout the product lifecycle. Mr. Kennedy of Honeywell explains the importance of automation, "*It used to be more manual, so we had more troubles in the past.*" As product and design chain complexity have increased, PLM has evolved to address the challenge. PLM has expanded in four dimensions (Figure 1), now encompassing a broader view or the product, more of the product lifecycle, a greater number of the people involved in product innovation, and more product-related processes.

Figure 1: Four Dimensions of PLM Expansion

PLM expanding to include a more complete view of the product is a tremendous boost in addressing complexity. PLM can now capture and manage both technical and commercial product information to keep it in sync. Now all of this information can be under revision and change control to ensure products are delivered as intended. For example, companies can link today's complex requirements to the associated design elements that deliver them to make sure all requirements are met and validated. This more full definition also helps address mechatronic challenges by enabling different design elements to be kept tightly in sync and configured. "*We have local systems for product design,*" explains Honeywell's Kennedy, "*We are moving to more common, centralized systems*." PLM offers strong support for individual design disciplines, but also support for combined disciplines, systems designs, and collaboration.

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The expansion to include more people helps significantly with globalization. With resources across the globe working concurrently on designs, it is even more important to have product information under control. PLM also offers support for collaboration with suppliers, including selective sharing of information to protect intellectual property (IP). Mr. Kennedy of Honeywell provides an example, "*Systems that don't talk between sites become more of a challenge, you need an enterprise view.*"

PLM also offers the ability to close the loop on the product lifecycle, and improve products by incorporating downstream feedback into new designs.

Lastly, expanding PLM to more facets of the product lifecycle is incredibly valuable to support global manufacturing, service, and lifecycle profitability. PLM also offers the ability to close the loop on the product lifecycle, and improve products by incorporating downstream feedback into new designs. As Mercury Marine's Bellio says, "*If you can close the loop, the payback is astronomical.*"

Conclusion

Products have grown in complexity, with no end in sight. The five dimensions of product complexity are direct results of today's market and manufacturing environment. Manufacturers must address these challenges or suffer from poor quality products, delayed time to market, and high lifecycle costs. As Fred Bellio of Mercury Marine sums up, "*If you don't have a handle on complexity, you will have a proliferation of new items and cost, and have a heck of a time keeping everything in sync.*"

Addressing product complexity requires PLM. Many of the complexities, such as mechanical and mechatronic challenges, can be addressed by the basics of PLM such as configuration management and change control. Other complexities, including global design, are aided by the basics as well. PLM also helps alleviate challenges in lifecycle profitability and global manufacturing, leveraging more advanced capabilities resulting from extending PLM to more people, expanding the view of the product, supporting more of the product lifecycle, and enabling more processes. Rick Kennedy of Honeywell sums up the opportunity. "*PLM offers really big gains in managing design complexity from systems design all the way through the product lifecycle. It provides the opportunity to develop much more robust designs, flexibility to make better design trade-offs, and allow designers to evaluate more options and their impacts so decisions are better and there is less chance of unplanned rework.*"

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Recommendations

Based on industry experience and research for this report, Tech-Clarity offers the following recommendations to:

- Implement the basics of PLM, including change management and configuration management. As Honeywell's Kennedy explains, "*If you didn't have change and configuration management controls in place, it would be a huge hole. I don't know how you would do business.*"
- Expand PLM to a broader view of the product, including the different engineering disciplines required for mechatronic designs.
- Extend PLM to support more phases of the product lifecycle, including upstream functions such as innovation and requirements gathering and downstream functions like manufacturing and service, breaking down functional silos. As Mercury Marine's Bellio points out. "*You need an integrated solution. It starts in concept and ends in service, and needs to be addressed at that level. Product success requires enterprise thinking.*"
- Include more people in product innovation, product development, and other product-related processes.

About the Author

Jim Brown is the President of Tech-Clarity, an independent research and consulting firm that specializes in analyzing the true business value of software technology and services. Jim has over 20 years of experience in software for the manufacturing industries, with a broad background including roles in industry, management consulting, the software industry, and research. His experience spans enterprise applications including PLM, ERP, quality management, service, manufacturing, and others. Jim is passionate about improving product innovation, product development, and engineering performance through the use of software technology and social computing techniques.

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