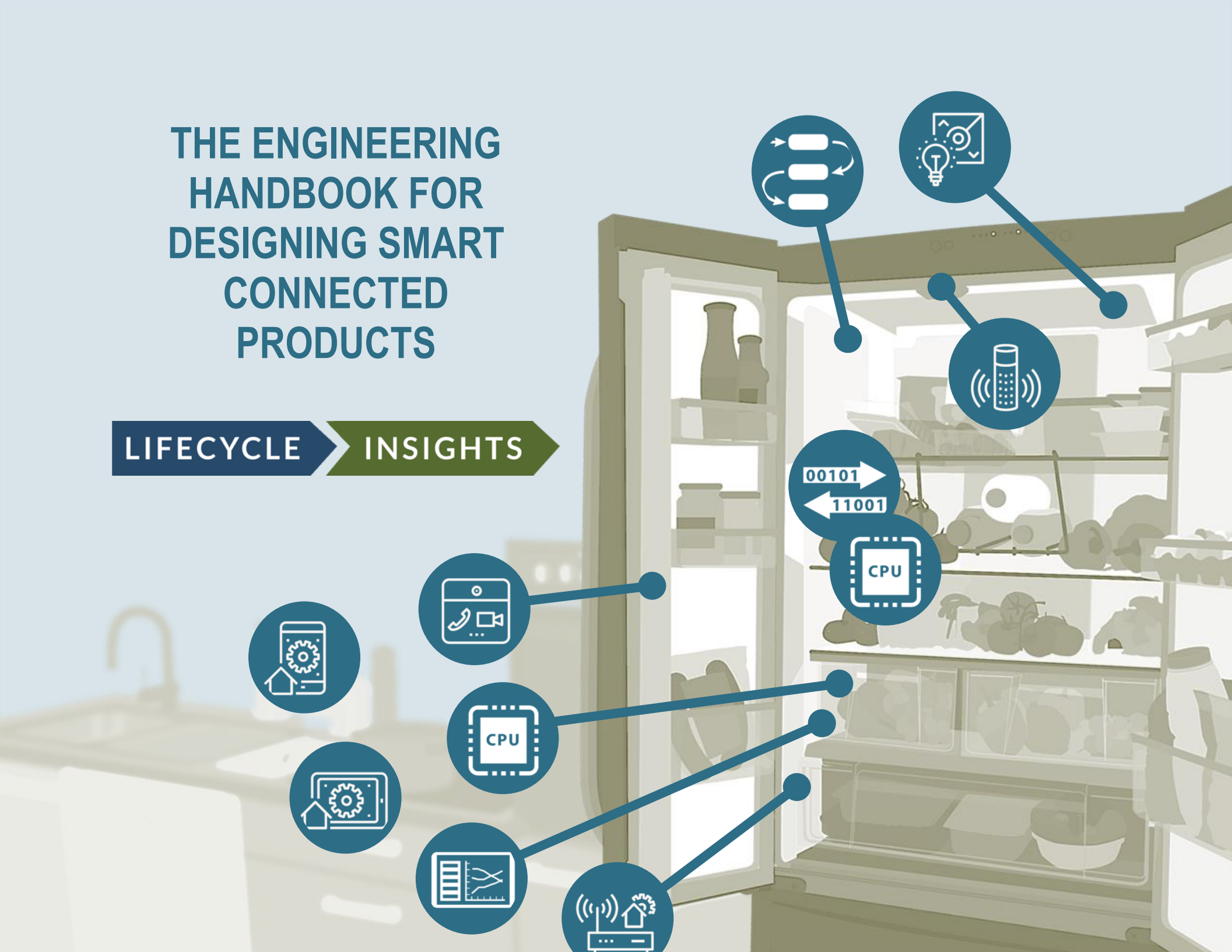
THE ENGINEERING HANDBOOK FOR DESIGNING SMART CONNECTED PRODUCTS

LIFECYCLE INSIGHTS



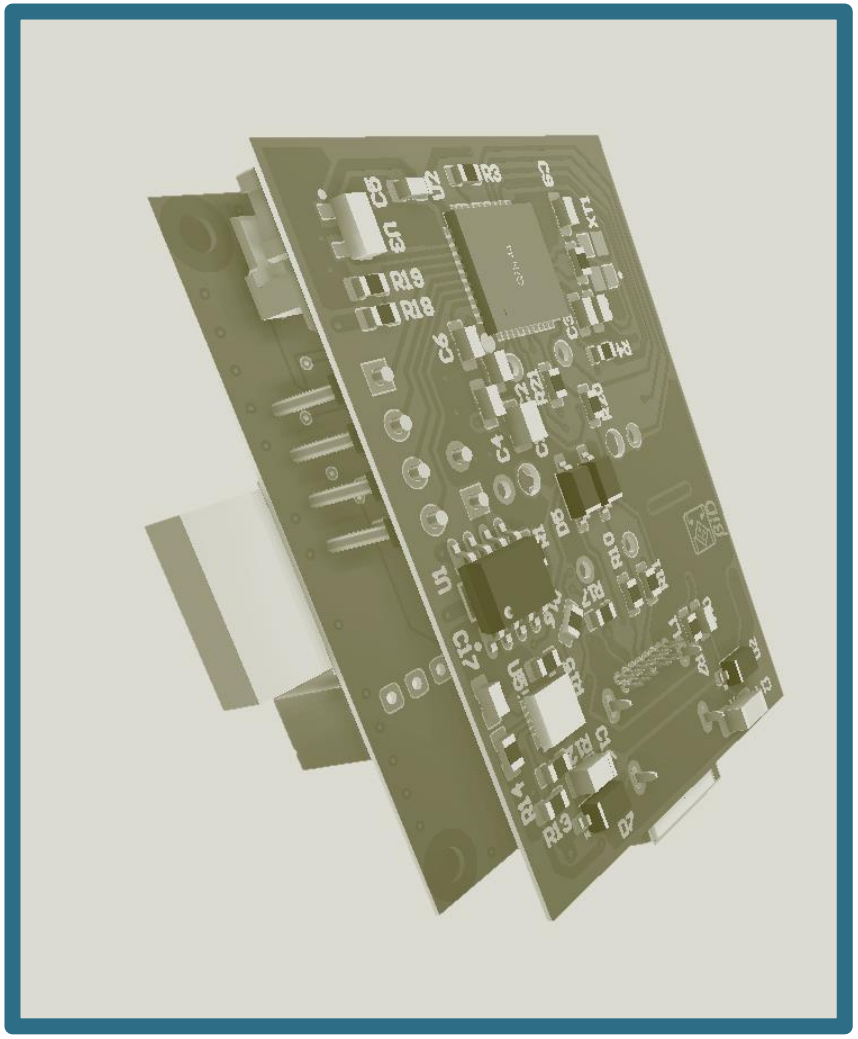
HOW DO YOU DEVELOP SMART CONNECTED PRODUCTS?

Today, the Internet of Things (IoT) is driving dramatic change. Some see it as an incredible opportunity, while others view it as a dire threat. Either way, companies who embrace the technology are using it to enable broader transformations. They use it to gain insight into product usage, remotely monitor products, and preemptively schedule maintenance calls.

However, the scope of the change is not limited to company operations after product delivery. The products themselves are also undergoing fundamental changes. To leverage the IoT, businesses are creating *smart, connected* offerings, and products traditionally made of mechanical components are now seeing an influx of sensors, antennas, circuit boards, embedded software, and complex wiring harnesses.

The transformation of products, of course, carries serious implications for engineering organizations. Design teams need new skills, processes, and technologies to develop smart, connected products on time and under budget. But what roles need to be filled? What new training is needed? How can streaming data be used? Exactly what processes need to be adopted? What new tools need to be acquired?

The purpose of this eBook is to answer these questions. It provides details on the trends driving companies to develop smart, connected products and explains how streaming data can be leveraged. It discusses the changes companies need to embrace to make the transition to a new age of smart products with less disruption. Read on to learn how your organization can navigate such a transformation.



THE NEW DEMANDS ON ENGINEERING TEAMS

In the IoT era, companies are transforming their products in two distinctive ways. They are making them 1) smarter and 2) more connected. These two changes require the development of new capabilities in the products, which will be discussed in this section.

MAKING PRODUCTS SMARTER

A smarter product typically features capabilities that manifest in some external way. For instance, it might interact intelligently with the user or autonomously react to changes in its environment or operation. The key is that the product senses something and reacts in an intelligent way.

The reason businesses produce smart products is typically to achieve some market advantage. That might be differentiation, thus staving off competitors. That might be the disruption of an existing market, unbalancing long-standing incumbents. That might be charging a price premium for innovative new features.

Regardless of the advantage a smart product enables, it needs a particular set of technology-enabled capabilities.

- It needs sensors to detect the environment or user interfaces to enable human interaction.
- It needs a communication network to send readings or commands to electronics.
- It requires processors and software embedded on circuit boards to interpret data and send commands to an interface or actuated components.
- It requires actuated components to exert physical control over the product or environment.

As companies transform their traditional offerings into smart ones, engineering organizations need the ability to develop and integrate these new technologies into their products. That means engineering organizations must learn to:

- Develop and place the right configuration of sensors into their products.
- Develop embedded software that exerts the right control characteristics for smart products.
- Design and place circuit boards and electrical systems into their products.
- Integrate all of these components into a functioning system.

MAKING PRODUCTS MORE CONNECTED

Transforming products to become more connected is dramatically different from making them smarter. Typically, connecting products means streaming data from sensors to digital storage on the Internet. Interestingly, a person using a connected product might never know it is connected since its key capabilities might never manifest in an external way.

Companies that connect their products often use streaming data to enable a variety of strategies. For some, it lets them transition to a product-as-a-service offering, where they charge a time-based fee for the product's use. For others, it means gaining more insight into how products are used and opening up new revenue streams for maintenance. For yet others, it is about learning which parameters of the product to improve upon in the next generation.

From an engineering perspective, connected products require a common set of technology-enabled capabilities.

- Sensors take readings from the product or its environment.
- Communication networks that transmit either to electronics, which process data before sending it to an antenna, or directly to an antenna for transmission.
- Antennas that communicate such readings through an Internet connection to a remote server, either in the cloud or to the company's server.

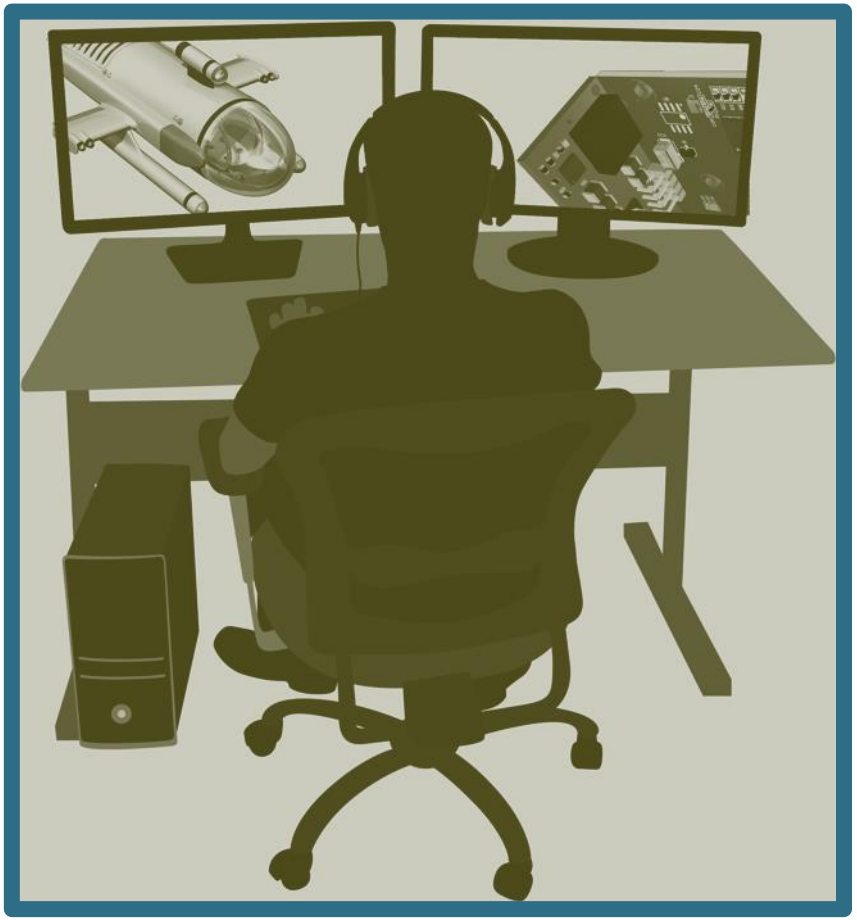
To make traditional products more connected, engineering organizations need a range of capabilities to integrate these technologies into their offerings. They must:

- Develop and place the right configuration of sensors into their products.
- Develop and place antennas so the product can connect to the internet and communicate sensor readings.
- Design and place optional circuit boards that process the readings into products.
- Design and route electrical systems through their products to enable communications.

From an engineering perspective, product connectivity presents its own challenges. You not only have to identify what data is important to stream to an IoT platform, but you must also determine the network bandwidth required. You must wrestle with where to host the data and how to secure it. Finally, it is critical that you figure out how to translate that data into conclusions that support the objective of the business. For engineering leaders, this is no easy task.

TAKEAWAYS: ENGINEERING IS CHANGING

Because of the dual demands to make products smarter and more connected, engineering organizations are being forced to undertake fundamental changes. They must expand their capability sets to develop and integrate new technologies into their products. That requires new skills, processes and design tools.



PUTTING STREAMING DATA TO WORK

Streaming data from connected products presents an incredible opportunity to enable new strategies for companies. This section reviews a number of those approaches.

IMPROVING SERVICE AND MAINTENANCE

One popular way in which organizations are leveraging streamed data is to improve upon the service and maintenance of their products. It lets businesses monitor product performance remotely and enables them to proactively service products that exhibit troubling readings instead of reacting to a product that fails in the field, which can result in downtime and consumer discontent.

The key to this approach is to recognize trends in the data that signal an impending failure or the need for preemptive service. This can be enabled with machine learning—software algorithms that look for data anomalies—as well as digital twins, which are virtual models that mimic the behavior of physical operating products.

From a business perspective, utilizing streaming data to preemptively schedule maintenance is a critical enabler to a product-as-a-service strategy, which supplies product capability for a service fee instead of requiring the customer to purchase a physical product. For one example, consider heating and cooling services provided for a monthly fee instead of requiring the user to buy HVAC equipment. For another, imagine airplane thrust covered by a monthly contract instead of requiring the purchase of turbine engines.

In both examples, uninterrupted service is the key to service payments without penalties. Proactive maintenance is a crucial enabler of this strategy.

IMPROVING CUSTOMER EXPERIENCES

Many discussions about connected products focus only on what can be done with streaming data once it is off the product. However, an alternative is to combine such sensor data with other publicly accessible data from the Internet to deliver unique features or capabilities. For example, a smart sprinkler system might not only enable remote activation but it could actually monitor weather forecasts and not water a lawn on days with rainy outlooks.

The key enabler in these scenarios is the ability to combine sensor data streamed from the product with information from data sources on the Internet. This capability is often delivered as part of IoT platforms based in the cloud. Logical conditions are defined either in that platform or with software on the product to make smarter decisions. Such capabilities can offer highly differentiated product capabilities.

IMPROVING PRODUCT PLANNING

Whenever a company plans a new product, it bases its requirements or features on a number of assumptions about how existing products are being used. Unfortunately, those assumptions can be wrong. When that happens, the entire product development effort fails because the underlying premise is off target. As a result, customers are presented with products they don't want or need.

In the IoT era, however, those assumptions can be replaced with data from connected products. Companies can instrument existing products with sensors and stream data that provide hard evidence of how a product is used and measurements of its operating environment. This lets them verify the actual usage or operation of a product instead of making assumptions.

For organizations planning a product family based on a modular architecture, such data can be a tremendous boon. Product planners and engineers can validate what options and variant capabilities are actually used and which are not. Such information is invaluable for making better decisions in the future.

UNFORESEEN BUSINESS CHANGES

Regardless of how you plan to use streaming data, note that there can be unforeseen consequences. Transitioning to a product-as-a-service strategy means that the company's revenue stream relies directly on the uptime of that service and the organization's ability to preemptively fix product issues before they break. Offering unique features based on the mashup of sensor data and Internet information requires consistent connectivity, otherwise the product can feel broken. Replacing assumptions with streaming data can eliminate a source of error, but that data needs context.

As your company goes through the transition to producing and delivering smart connected products, identify the critical enablers and differentiating features of the offering. Develop your business case around this new offering. Furthermore, note how flaws could undermine the success of your new approach.

Lastly, note that while connected products, streaming data, and the IoT *can* transform your business, they *don't have* to transform your business. You can apply these capabilities to your current business model and products without drastic changes. However, be aware that customer expectations might change. There are many implicit and explicit implications for smart, connected products.

TAKEAWAYS

Streaming data can enable a range of new strategies, including:

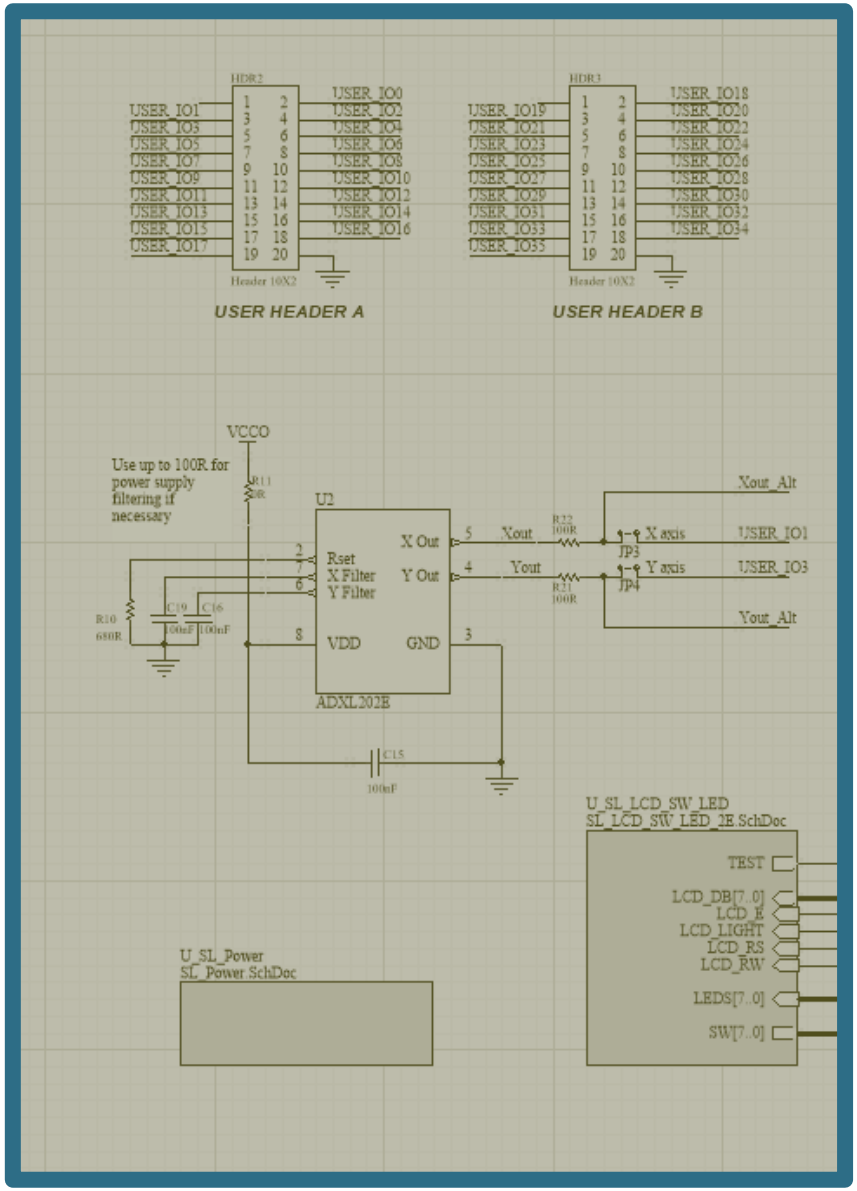
- Remote monitoring of products to power preemptive service. This can be used in products-as-a-service approaches.
- Sensor data can be mashed up with internet data to provide new product features, differentiating the offering.
- Sensor data can replace assumptions early in the development process, reducing the chance of developing an off-the-mark product.
- Offering smart connected products can result in unforeseen business consequences. Proceed with a business case of how it can improve your company, but also identify shortcomings and flaws.

DEVELOPING ELECTRICAL SYSTEMS AND ELECTRONICS

Features of modern products, whether they are smart or connected, rely on electronics and electrical systems, including sensors, antennas, circuit boards, and cabling harnesses. As companies transition to making these kinds of products, they must extend or improve their development capabilities.

PEOPLE, PROCESS AND TECHNOLOGY CHANGES

- **Hiring or Training Electrical Design Skills:** Many makers today can hack their way into designing mechanical components. But designing these items within a system requires specific electrical design knowledge and skills. Organizations that seek to develop internal competencies in this area must hire electrical engineers or invest in a moderate amount of engineering training. There are no good shortcuts around this step.
- **Verification and Validation Processes:** Modern electronics and electrical systems require specific steps to ensure they fulfill their requirements. Technologies can assist in this area by digitally checking new designs. However, validation is a critical step before reaching system-level prototyping and testing.
- **Acquiring the Right Design Tools:** Electrical Computer-Aided Design (ECAD) and Interconnect design tools are needed to design these items, and they're well worth the investment. Ensuring tight integration between Mechanical Computer-Aided Design (MCAD) and ECAD tools is also critical, as iterations need to be exchanged during the course of development. Data Management is also critical to track configurations of systems. A tightly integrated ecosystem of tools is needed to be successful.



OUTSOURCING TO SUPPLIERS

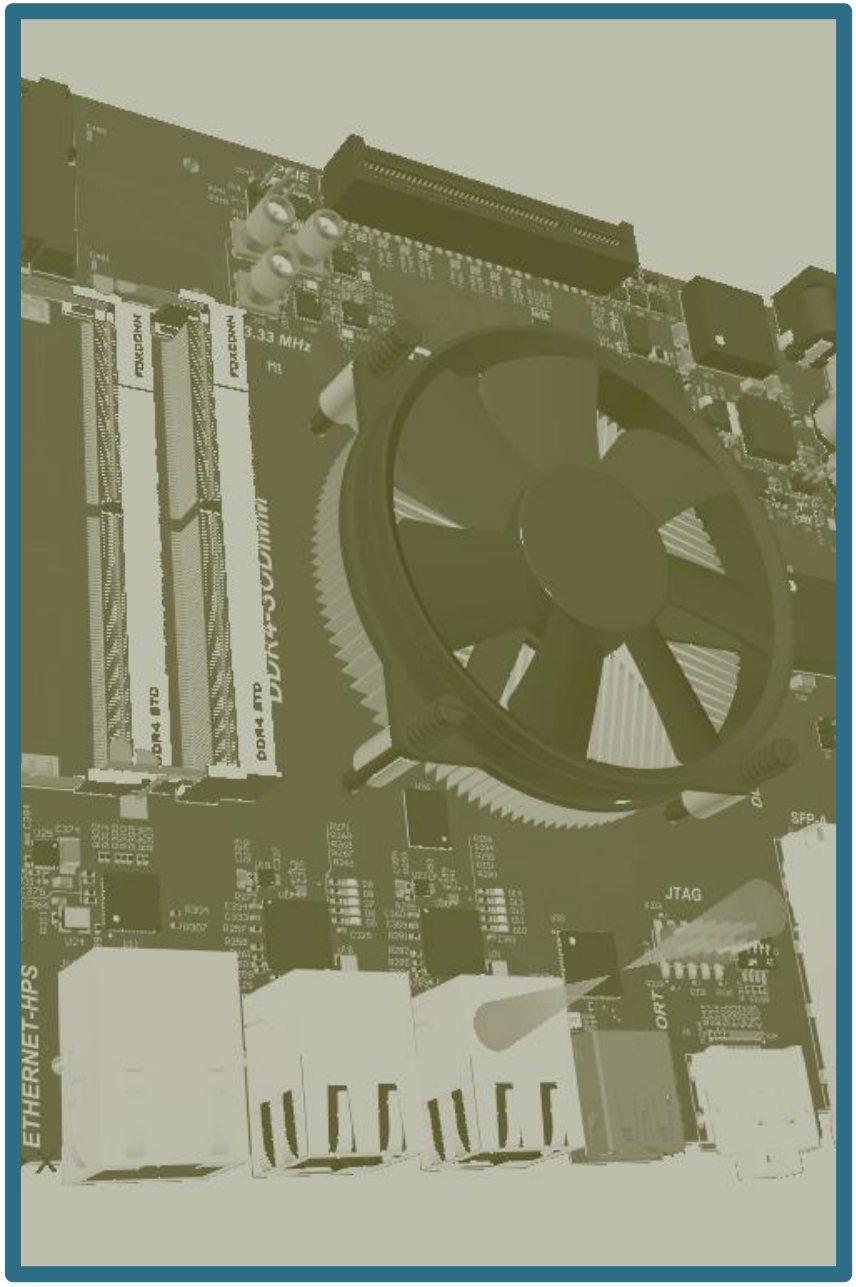
An alternative to developing these competencies internally is to treat these areas as a black box and outsource them to a third party. This can be successful if your organization can tightly define and manage requirements focused on power, control, signal integrity, and other characteristics of these systems.

Note, however, that one of the largest challenges of development systems in smart, connected products is making sure that your embedded software runs on your target electronic hardware. You must carefully manage this risk if you outsource the electronics and electrical aspects of such systems.

Lastly, if your organization pursues this approach, it must understand how to integrate electronics into system, not just with embedded software. Prototyping and testing systems and identifying failure points is critical.

TAKEAWAYS

It is possible to develop these competencies internally. Note, however, that outsourcing such work, perhaps as an entire control system to a supplier, is a viable alternative. In either approach, internal abilities for requirements definition, systems design and testing are non-negotiable competencies.



DEVELOPING EMBEDDED SOFTWARE

The intelligence in smart connected products comes from embedded software, which powers control systems and processes sensor data sent to IoT platforms. This is another important competency for the development of modern products.

PEOPLE, PROCESS AND TECHNOLOGY CHANGES

- **Hire Coders or Enable Democratization:** There are a couple options to acquiring the skills for embedded software development. One option is to hire or train traditional software developers. The second option is to empower control engineers with graphical programming tools to model the software and auto-generate code. The latter requires an embedded software engineer to review the auto-generated code prior to testing.
- **Model-Based Development:** A key step in embedded software development is verifying that the code runs on target electronic hardware. If you wait until you have a physical prototype of a circuit board, a failure and re-spin will likely cause significant development delays. As an alternative, your organization can digitally verify compatibility through a series of progressive steps called Model-Based Development. These steps, running from Model-in-the-Loop through Hardware-in-the-Loop, ensure everything works together long before the board prototype arrives. Adopting this process is key for any organization developing smart, connected products.
- **Software Development Tools:** An ecosystem of tools is needed to develop embedded software. To produce code, embedded software developers need Integrated Development Environment (IDEs), which are commonly open source, or control engineers need graphical programming solutions. To manage the code, Software Configuration Management is required. To manage code through its lifecycle, Application Lifecycle Management (ALM) can also be useful.

OUTSOURCING TO SUPPLIERS

Much like electronics and electrical systems, the development of embedded software can be outsourced and integrated during the development process. Management of requirements—and their enforcement with suppliers—over characteristics such as code size, efficiency and control is necessary. Furthermore, if you pursue this path, you must require the supplier to use a process like Model-Based Development to avoid delays at the end of development. Lastly, systems engineering capabilities are essential to manage change throughout design and to verify that everything works during prototyping and testing.

TAKEAWAYS

Coding for control systems can be powered by developers or controls engineers. However, outsourcing this work to a supplier is also an alternative, perhaps as an entire control system. Either way, requirements management, systems design, and testing are non-negotiable competencies.

DEVELOPING IOT PLATFORMS AND PRODUCT CONNECTIVITY

All connected products stream data to an IoT platform, whether that resides somewhere in the cloud or within a company's data center. Either way, new capabilities must be adopted to support an IoT platform.

PEOPLE, PROCESS AND TECHNOLOGY CHANGES

- **Intersection of IT and Engineering:** The development and management of IoT platforms presents an interesting challenge in terms of roles. It is an enterprise system that holds key data, yet it requires expertise to ensure that a growing number of smart connected products can, in fact, connect to it. A new role, one that is part IT and part engineering, is emerging to fill the gap. Companies need to support someone who can grow with the job, as it really hasn't existed on a large scale in the market yet.
- **Digitally Prototyping the IoT Platform:** Companies can instrument products with sensors and start streaming data to an IoT platform. But are they streaming the right information? Are they able to draw the right conclusions from that data? Answering those questions during prototyping, or worse yet after shipping product, is likely to yield poor outcomes. Instead, companies will be streaming data from digital simulations to IoT platforms in an effort to prove them out virtually earlier instead of physically later.
- **Flexibility and Agility in IoT Platforms:** Today's reality is that many companies need to experiment with smart connected products before they dial in those efforts to see the right outcomes. To support that need to make changes, companies should select IoT platforms that enable fast and easy change. This flexibility and agility is a requirement for what is sure to be an era of experimentation.

OUTSOURCING TO SUPPLIERS

IoT platforms will hold crucial data that has been streamed from products, some of which is specific to sites and customers. With data privacy and the prevalence of hacking at the forefront of everyone's mind, it is crucial that companies take care in managing and protecting that data.

Developing and managing IoT platforms can be outsourced. However, companies should carefully consider the consequences of trusting a third party to manage this crucial system and its data.

TAKEAWAYS

Ultimately, the data you collect from products will become one of the most critical, if not the most critical, assets to your company. Your company needs to have complete ownership of that data. Finding the right competencies to manage it is of the utmost importance as opposed to outsourcing it.

DEVELOPING INTEGRATED SYSTEMS

Ultimately, all of the items in a product must come together as a functioning whole. To ensure that happens without multiple costly rounds of prototyping requires specific system engineering competencies.

PEOPLE, PROCESS AND TECHNOLOGY CHANGES

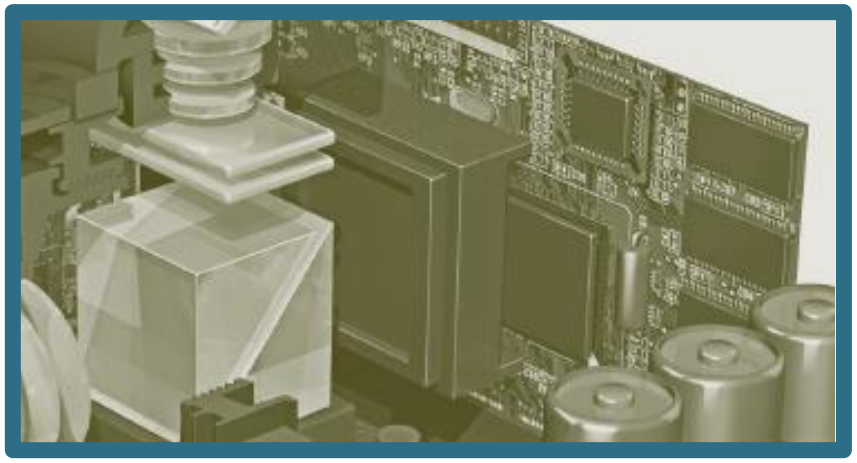
- **Obtaining a Systems Perspective:** System engineers come from a variety of engineering domains. However, one thing they have in common is a disciplined approach towards development supported by specific processes and tools. You can fill these positions by hiring but, with the right support system, the knowledge and skills for the job can be learned or taught.
- **Requirements-Functions-Logical-Physical (RFLP):** The RFLP process sits at the core of system engineering. It represents a means of defining the scope of the development of a product in terms of requirements and the progressive definition of the engineering solution. The allocation of one step to the next also supports full traceability from one end to another. In turn, engineers must be able to assess a potential change, either from requirements or from physical items, and understand its impact. Approaches that use a single model to support this effort are called Model-Based System Engineering (MBSE).
- **System Design Tools:** Tools that quickly and easily define the RFLP aspects of a product offer considerable support for system efforts. In addition to those tools, system modeling and simulation solutions can analyze the performance of such designs. Both tools provide value but serve different purposes.

OUTSOURCING TO SUPPLIERS

Technically, businesses can outsource system design to third parties. In fact, some suppliers have deep expertise in this domain; however, it is ill advised. System engineering plays a key role in ensuring that the designs from different domains are architected correctly and are integrated seamlessly before prototyping and testing. It is a core competency to developing smart, connected products that organizations should not cede to other parties.

TAKEAWAYS

Simply put, system engineering is crucial to developing smart, connected products. Developing this competency requires hiring or training system engineers internally, adopting an RFLP process, and implementing system design tools.



SUMMARY AND CONCLUSION

Sometimes seen as an opportunity, sometimes seen as a threat, the Internet of Things is driving many companies to develop smart, connected products. As a result, the composition of products is changing with an influx of sensors, antennas, circuit boards, embedded software, and wire harnesses.

THE NEW DEMANDS ON ENGINEERING TEAMS

It is no easy task to develop and integrate software, electronics, and electrical systems into traditional mechanical products. Engineering organizations must find ways to build new design competencies or find suppliers they can trust as development partners. This demands new roles, new processes, and new tools.

PUTTING STREAMING DATA TO WORK

Linking smart, connected products to IoT platforms provides companies access to streaming data that empower a wide range of new strategies and business models.

Companies can move to a proactive maintenance approach or even adopt a product-as-a-service business model. They can mash up streaming data with Internet accessible data to offer differentiated features or services. They can even use streaming data to replace the assumptions traditionally used at the beginning of development for product planning.

While each of these scenarios can deliver tremendous value, companies should be aware that offering smart, connected products can produce unforeseen business changes. Organizations should carefully plan for such offerings accordingly.

DEVELOPING SMART CONNECTED PRODUCTS

To develop smart, connected products, engineering organizations must acquire competencies across software, electrical, and electronic systems and IoT domains. This includes:

- Hiring new or training existing personnel with skills and knowledge specific to that engineering domain.
- Implementing new processes specific to that discipline or that help with integration across engineering domains.
- Adopting new tools and systems that enable automated design and validation.

Electrical systems, electronics, and embedded software can be outsourced to suppliers. We specifically recommend you develop and maintain competencies for systems and IoT platforms *inside* your company instead of outsourcing them. These two areas are crucial to streamlining development and avoiding errors that could significantly delay project deadlines.

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