

interactions with suppliers, sales interactions, customer service visits, and so on. Firms supplemented that data with information gathered from surveys, research, and other external sources. By combining the data, companies knew something about customers, demand, and costs—but much less about the functioning of products. The responsibility for defining and analyzing data tended to be decentralized within functions and silos. Though functions shared data (sales data, for example, might be used to manage service parts inventory), they did so on a limited, episodic basis.

Now, for the first time, these traditional sources of data are being supplemented by another source—the product itself. Smart, connected products can generate real-time readings that are unprecedented in their variety and volume. Data now stands on

and performance. Knowing that a customer's heavy use of a product is likely to result in a premature failure covered under warranty, for example, can trigger preemptive service that may preclude later costly repairs.

DATA ANALYTICS. As the ability to unlock the full value of data becomes a key source of competitive advantage, the management, governance, analysis, and security of that data is developing into a major new business function.

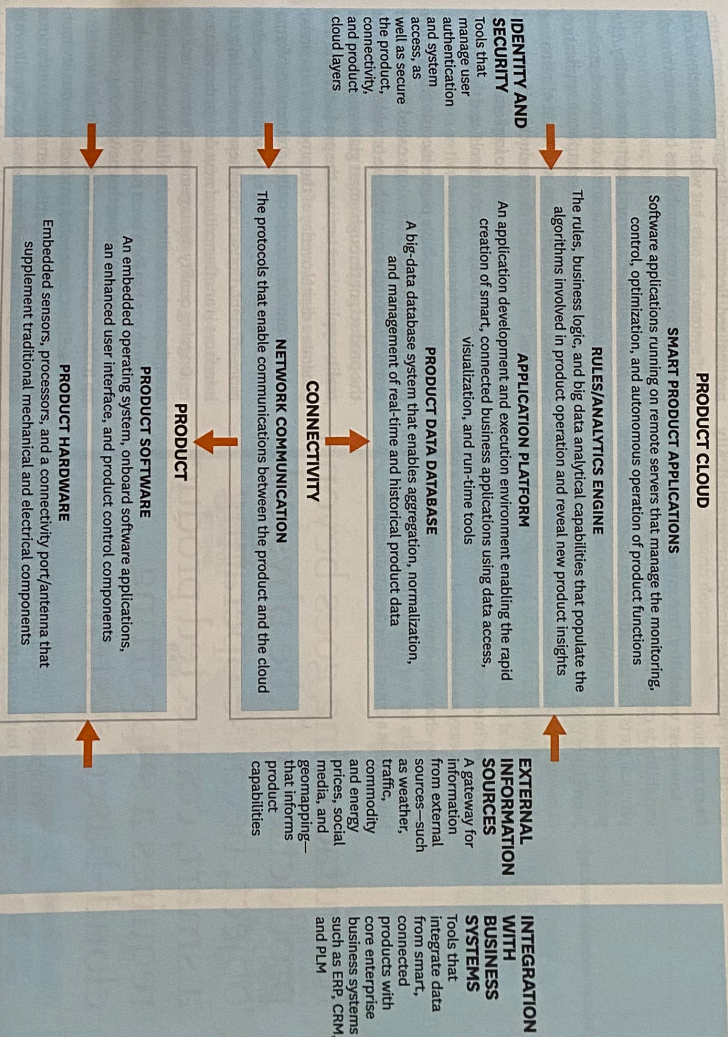
While individual sensor readings are valuable, companies often can unearth powerful insights by identifying patterns in thousands of readings from many products over time. For example, information from disparate individual sensors, such as a car's engine temperature, throttle position, and fuel consumption, can reveal how performance correlates with the car's engineering specifications. Linking combinations of readings to the occurrence of problems can be useful, and even when the root cause of a problem is hard to deduce, those patterns can be acted on. Data from sensors that measure heat and vibration, for example, can predict an impending bearing failure days or weeks in advance. Capturing such insights is the domain of big data analytics, which blend mathematics, computer science, and business analysis techniques.

Big data analytics employ a family of new techniques to understand those patterns. A challenge is that the data from smart, connected products and related internal and external data are often unstructured. They may be in an array of formats, such as sensor readings, locations, temperatures, and sales and warranty history. Conventional approaches to data aggregation and analysis, such as spreadsheets and database tables, are ill-suited to managing a wide variety of data formats. The emerging solution is a "data lake," a repository in which disparate data streams can be stored in their native formats. From there, the data can be studied with a set of new data analytics tools. Those tools fall into four categories: descriptive, diagnostic, predictive, and prescriptive. (For more details, see the exhibit "Creating New Value with Data.")

To better understand the rich data generated by smart, connected products, companies are also beginning to deploy a tool called a "digital twin." Originally conceived by the Defense Advanced Research Projects Agency (DARPA), a digital twin is a 3-D virtual-reality replica of a physical product. As

THE NEW TECHNOLOGY STACK

smart, connected products require companies to build and support an entirely new technology infrastructure. This "technology stack" is made up of multiple layers, including new product hardware, embedded software, connectivity, a product cloud consisting of software running on remote servers, a suite of security tools, a gateway for external information sources, and integration with enterprise business systems.



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par with people, technology, and capital as a core asset of the corporation and in many businesses is perhaps becoming the decisive asset.

This new product data is valuable by itself, yet its value increases exponentially when it is integrated with other data, such as service histories, inventory locations, commodity prices, and traffic patterns. In a farm setting, data from humidity sensors can be combined with weather forecasts to optimize irrigation equipment and reduce water use. In fleets of vehicles, information about the pending service needs of each car or truck, and its location, allows service departments to stage parts, schedule maintenance, and increase the efficiency of repairs. Data on warranty status becomes more valuable when combined with data on product use

data streams in, the twin evolves to reflect how the physical product has been altered and used and the environmental conditions to which it has been exposed. Like an avatar for the actual product, the digital twin allows the company to visualize the status and condition of a product that may be thousands of miles away. Digital twins may also provide new insights into how products can be better designed, manufactured, operated, and serviced.

Transforming the Value Chain

The powerful new data available to companies, together with new configurations and capabilities of smart, connected products, is restructuring the traditional functions of business—sometimes radically. This transformation started with product

development but is playing out across the value chain. As it spreads, functional boundaries are shifting, and new functions are being created.

PRODUCT DEVELOPMENT. Smart, connected products require a fundamental rethinking of design. At the most basic level, product development shifts from largely mechanical engineering to true interdisciplinary systems engineering. Products have become complex systems that contain software and may have as much or more software in the cloud. That's why design teams are shifting from a majority of mechanical engineers to a majority of software engineers, and some manufacturers, like GE, Airbus, and Danaher, are establishing offices in software-engineering hubs like Boston and Silicon Valley.