

Manufacturing goes beyond production of the physical object, because operating a smart, connected product requires a supporting cloud-based system.

Smart, connected products also call for product design principles that depart dramatically from tradition:

Low-cost variability. In conventional products, variability is costly because it requires variation in physical parts. But the software in smart, connected products makes variability far cheaper. For example, John Deere used to manufacture multiple versions of engines, each providing a different level of horsepower. It now can alter the horsepower of a standard physical engine using software alone. Similarly, digital user interfaces can replace dials and buttons, making it easy and less expensive to modify a product by, say, changing control options. Meeting customer needs for variability through software, not hardware, is a critical new design discipline.

Variability is needed not only across customer segments but also across geographies. Software also makes it easier to localize products for different countries and languages. However, emerging local regulations for data standards, such as those governing the transmission of data across national boundaries, require duplication of data storage infrastructure or applications. Such regulations are introducing new country and regional differences, sometimes for political reasons.

Evergreen design. In the old model, products were designed in discrete generations. The new product incorporated a full set of desired improvements, and the design was then fixed until the next generation. Smart, connected products, however, can be continually upgraded via software, often remotely. Products also can be fine-tuned to meet new customer requirements or solve performance issues. The performance of ABB Robotics' industrial machines, for example, can be remotely monitored and adjusted by end users during operation. Companies

can release new features that are works-in-process, not finalized. Recently, Tesla began putting an "autopilot" system in its cars, but with the intention of enhancing the system's capabilities over time through remote software updates.

New user interfaces and augmented reality. The digital user interface of a smart, connected product can be put into a tablet or smartphone application, enabling remote operation and even eliminating the need for controls in the product itself. As noted, these interfaces are less costly to implement and easier to modify than physical controls, and they enable greater operator mobility.

Some products have begun incorporating a powerful new interface technology called "augmented reality." Through a smartphone or tablet pointed at the product, or through smart glasses, augmented reality applications tap into the product cloud and generate a digital overlay of the product. This overlay contains monitoring, operating, and service information that makes supporting or servicing the product more efficient. Constructing these powerful digital interfaces is another critical new design discipline.

Ongoing quality management. Testing that tries to replicate the conditions in which customers will use products has long been part of product development. The aim is to ensure that new offerings will live up to their specifications and to minimize warranty claims. Smart, connected products take quality management several steps farther, enabling continuous monitoring of real-world performance data, allowing companies to identify and address design problems that testing failed to expose. In 2013, for example, batteries in two Tesla Model S cars were punctured and caught fire after drivers struck metal objects in the road. The road conditions and speeds leading to the punctures had not been simulated in testing, but Tesla was able to reconstruct them. The company then sent a software update to all vehicles that would raise their suspension under those conditions, significantly reducing the chances of further punctures.

Connected service. Product designs now need to incorporate additional instrumentation, data collection capability, and diagnostic software features that monitor product health and performance and warn service personnel of failures. And as software increases functionality, products can be designed to allow more remote service.

Support for new business models. Smart, connected products let companies switch from transactional

selling to product-as-a-service models. However, this shift has product design implications. When a product is delivered as a service, the responsibility for and associated cost of maintenance remain with the manufacturer, and that can alter several design parameters. This is especially true when multiple customers share the product—as is the case at Smooove, a bike-sharing service in France. Smooove has designed its smart, connected bikes with chainless driveshafes, puncture-resistant tires, and anti-vandal nuts to improve durability and prevent theft. Products delivered as services must also capture usage data so that customers are appropriately charged. This requires clear thinking about the type and location of sensors, what data will be gathered, and how often it should be analyzed. When Xerox evolved from selling copiers to charging by the document, it added sensors on the photoreceptor drum, feeder output tray, and toner cartridge to enable accurate billing and facilitate the sale of consumables like paper and toner.

System interoperability. As products become components of broader systems, the opportunities for design optimization multiply. Through codesign, companies can simultaneously develop and enhance hardware and software across a family of products, including those of other companies. Take Nest Labs' self-learning thermostat. It was designed with an application programming interface that allows it to exchange information with other products, such as Kevo's smart lock. When the home owner enters the house, the Kevo lock communicates that to the Nest thermostat, which then adjusts the temperature to the home owner's preference.

MANUFACTURING. Smart, connected products create new production requirements and opportunities. They may even shift final assembly to the customer site, where the last step is loading and configuring software. But more radical still, manufacturing now goes beyond the production of the physical object, because a functioning smart, connected product requires a cloud-based system for operating it throughout its life.

Smart factories. The new capabilities of smart, connected machines are reshaping the operations of manufacturing plants themselves, where machines increasingly can be linked together in systems. In new initiatives like Industrie 4.0 (in Germany) and Smart Manufacturing (in the United States), networked machines fully automate and

CREATING NEW VALUE WITH DATA

Data from smart, connected products is generating insights that help businesses, customers, and partners optimize product performance. Simple analytics, applied by individual products to their own data, reveal basic insights; more-sophisticated analytics, applied to product data that has been pooled into a "lake" with data from external and enterprise sources, unearth deeper insights.

