DIGITAL WORLD SPAWNS IDENTICAL

To understand why manufacturers are fascinated by digital twins—exact digital replicas of products, machines, processes, or even entire factories—consider a packaging line that engineering software provider Maplesoft helped create.

Nondisclosure agreements prevent Paul Goossens, Maplesoft's vice president of engineering solutions, from mentioning the machine's creator, but he cannot stop talking about what makes it unusual.

"Packaging machines are amazing," he explained. "They're complex machines that pick up and cut pieces of cardboard, fill them, and seal them off. This is all done traditionally with complex mechanisms driven by a single motor."

Robots are replacing those motor-drive-gear-operated systems, Goossens said. The robots perform the same cutting, bending, and sealing tasks, but their arms are driven by independently controlled servomotors.

"The old machines are much cheaper to build," he said, "but they can only do one thing. So, if you had a new package, you either had to re-engineer your machine or scrap it. With robots, it's simply a matter of changing the packaging profiles and the software parameters."

Still, reprogramming robots takes time. In the past, an engineer might have used software to simulate how the line would handle the new packaging, but eventually he or she would have to pull those robots off the line. Then the engineer would test and tweak the movement of cardboard through the machine and the ability of the robotic arms to make and package containers, all the while trying to whittle fractions of seconds off each cycle.

A digital twin goes one step beyond conventional models. It models the robotic line with such high fidelity, the engineer can do all this in the virtual world. After adjusting the model's profiles and operating

Digital twins compare manufacturing process to models to find problems early.
Photo: Courtesy of Siemens

TWINS

Why stop at simulating a virtual product? Simulating the factory floor—creating a digital twin—can speed and customize production and make for a more perfect product.

BY JEAN THILMANY

parameters, the engineer simply exports the profiles and parameters to the control system of the physical equipment. Theoretically, at least, it should run perfectly the first time.

"That alone will certainly disrupt the packaging machine industry," Goossens said. "That's the future, and it's certainly where digital twins for large machines will end up."

Yet this is clearly not the end for digital twin technology. In fact, simulating individual machines is only the beginning. Because the real power of a digital twin is not that it optimizes a single machine, but that it interacts with the digital twins of every piece of equipment in a factory and the digital twin of every product those machines make.

Nor is it limited to optimizing those production processes in the virtual world. Digital twins run in tandem with their highly instrumented physical twins, fed by data by from actual operations. By comparing the output of the digital and physical systems, engineers can quickly spot problems before they arise, avoid bottlenecks, and find new ways to boost throughput and reduce costs.

In short, digital twins are the foundation of tomorrow's smarter workplace.

CHEAP BYTES

Digital twins may seem like the buzzword du jour, but the concept dates back 15 years, to John Vickers, NASA principal technologist in advanced manufacturing, and Michael Grieves, now executive director of Florida Institute of Technology's Center for Advanced Manufacturing and Innovative Design.

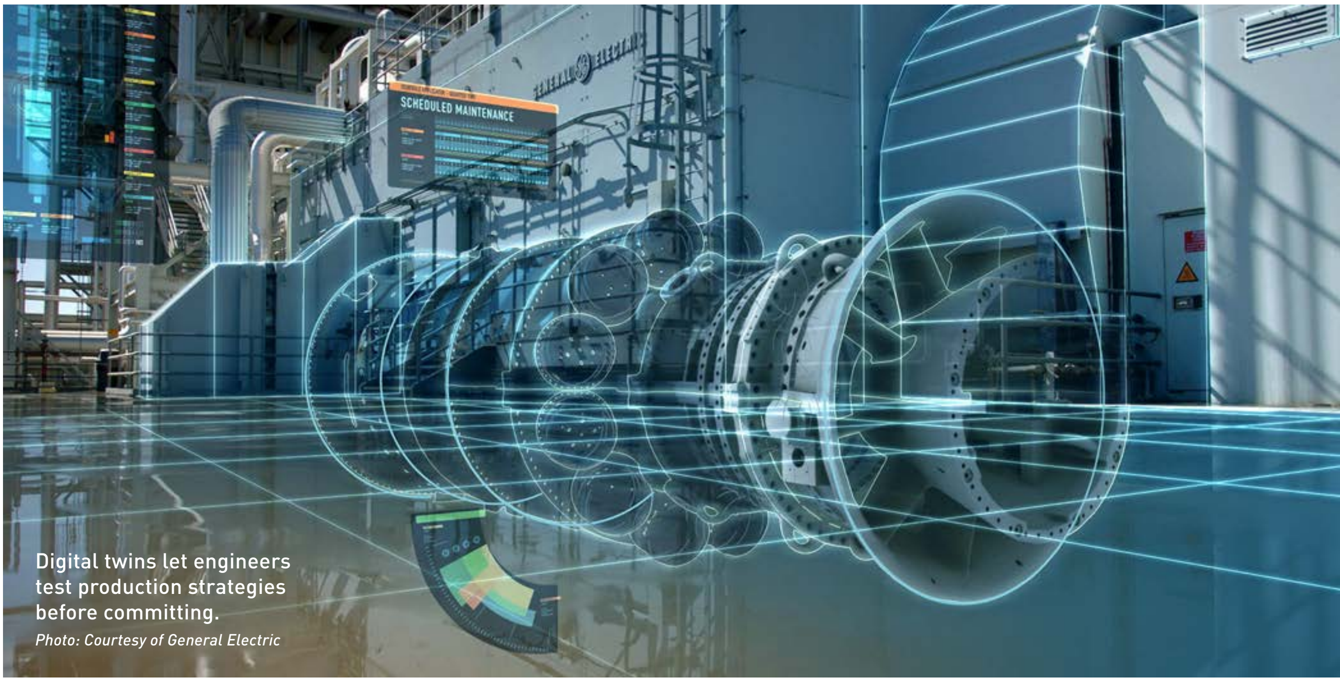
Their premise was simple: A digitally modeled system is really composed of two systems, a physical system and a virtual system that contains all the information about the physical system. They can exist for products and for processes.

Engineers have used product models for decades, but only recently have they achieved the extraordinary fidelity needed for digital twins. "In industries like automotive, we can define a big chunk of our products geometrically such that it is almost impossible to determine whether a representation is virtual or physical," Grieves said.

Product models slash development time by letting engineers build and test virtual prototypes to optimize design and cost. In 2002, Grieves proposed applying the same approach to manufacturing processes.

"I think the original concept of the digital twin is one of moving from trial and error on the physical side to doing as many things as you can with bytes," Grieves said. "The key is trading off expensive atoms for cheap bytes to the extent you can, so you can manufacture the product more efficiently and less expensively."

Conceptually, it is not much of a jump from



Digital twins let engineers test production strategies before committing.
Photo: Courtesy of General Electric

testing product designs to simulating manufacturing processes. In fact, many software programs do something similar today. What makes digital twins different is their fidelity and their ability to handle large amounts of data in real time.

Even modest factories are complex, and they have far fewer constraints than any complex product designed to operate in a specific way. In a factory, operating procedures are always changing. Even a simple drill press might bore aluminum one day, then switch bits, speed, and coolant for steel the next. A modern factory might make many products, and the flow of materials from machines through assembly stations will change with them.

A factory's digital twin must be robust enough to capture those changes, plus all relevant data from each operation. That takes massive IT horsepower. Fortunately, networked PC's have grown more powerful and manufacturers can now tap the cloud to store and analyze factory data using cognitive computing programs.

Modeling tools have also advanced, especially their ability to generate "lightweight" models. "We can select the geometry, characteristics, and attributes we require without carrying around unnecessary details," Grieves explained in a 2014 paper. "This dramatically reduces the size of the models and allows for faster processing."

Reducing data requirements lets digital twins visualize and simulate complex systems without drowning in a flood of extraneous real-time data.

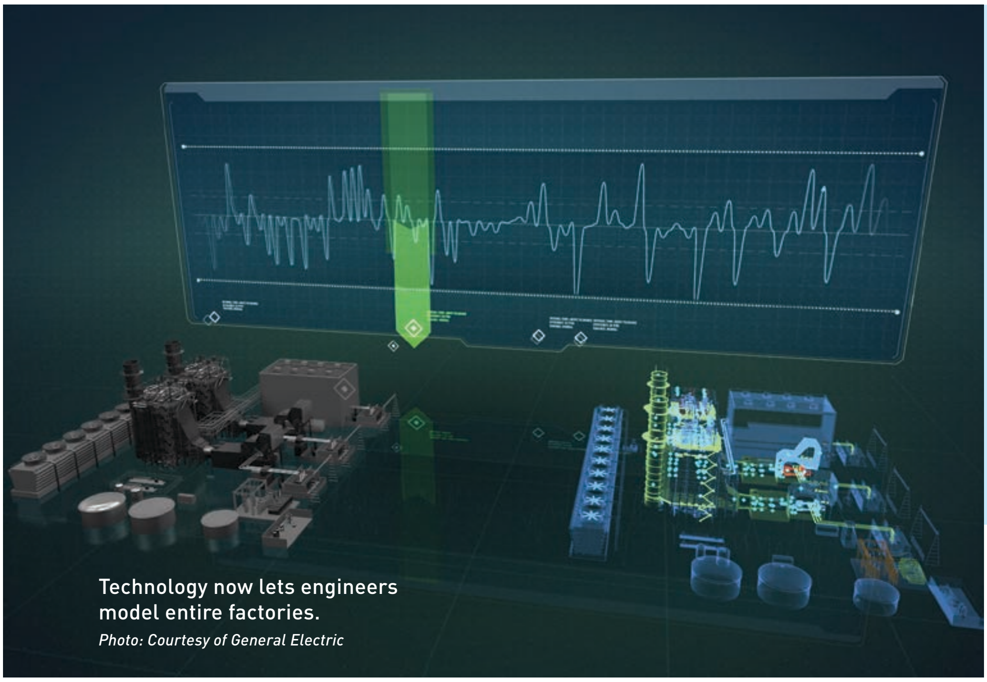
It takes highly instrumented equipment to supply that data. While manufacturers have been adding sensors to the shop floor for decades, the Internet of Things is making it cheaper and easier to collect up-to-the-minute factory data for performance analysis, said Matt Nielsen. He is a principal engineer at General Electric.

GE's "Brilliant Factory" is based on digital twins and the IoT data and cloud analytics needed to feed those models. "Plants are always changing, people are moving around, machines break and lines slow down," Nielsen said. "The digital twin will only work if it reflects the reality of the shop floor."

OPTIMIZED PROCESSES

Smart factories, like GE's Brilliant Factory and Siemens' competing Industrie 4.0, need both types of digital twins—product and process—to work.

Digital product models contain each component that goes into a product, from screws and welds to plastic shapes and machined metals. The digital twins that drive a factory have an associated bill of process for each of those components. This "instruction manual" describes the steps needed to produce and assemble those components into the final product, Alastair Orchard, vice president of digital enterprise for Siemens PLM, explained. Product and



Technology now lets engineers model entire factories.

Photo: Courtesy of General Electric

THE DIGITAL TWIN WILL ONLY WORK IF IT REFLECTS THE REALITY OF THE SHOP FLOOR.

—Matt Nielsen, principal engineer at General Electric

Digital twins will make it easier to evaluate production options.
Photo: Courtesy of Maplesoft

process twins work together.

"The digital twin can provide the manufacturing execution system with step-by-step instructions for making that product," Orchard said. "Our MES system can reference that instruction manual and perform all the coordination tasks to guide the product through the factory, setting up machines on the fly, and check that each step is done correctly."

The twins let engineers test-drive new processes. They could, for example, add a new machine to their virtual line and see how it affects output of specific products, or test whether relocating equipment or readjusting workflow between machines improves output. The result is not just an optimized machine, but an optimized process, Maplesoft's Goossens said. He envisions laser-scanning an entire factory to model its infrastructure, then dropping digital twins of machinery and logistics systems into it.

"We'll do thousands of virtual production runs to see if we really did design this product with manufacturing in mind," he said. "We can run a simulation where we put gloves on the employees and see if they can still assemble the product, or create assembly cells that combine collaborative robots and people and see if that helps."

Once the physical line is up and running, its sensors will send operating and inspection data to the factory's digital twins. These models provide a detailed view of factory operations. By looking for unexpected variances between actual and simulated data, engineers can probe for potential problems that might reduce operating rates or quality.

Digital twins also support greater automation, Orchard said. As orders come in, the system will make sure the proper parts are in inventory, schedule machine time, and route components from workstation to workstation with only minimal human intervention. Each step of the way, the plant would autonomously check product and machine specs against their digital twins to ensure each operation is carried out correctly and that no equipment is drifting out of tolerance.

PEDAL TO THE METAL

That's the theory, anyway. The fully connected factory of digital twins linked with IoT sensors and cloud analytics is still a work in progress. Yet this has not stopped engineers and manufacturers from simulating some operations with existing tools.

Italian carmaker Maserati, for example, created a virtual model of the production line that would build its new sports sedan, the Ghibli—while still designing the car digitally.

This interplay between product and process digital twins ensured Maserati that its factory could produce and assemble the parts its designers had envisioned, said Massimo Anfosso, Maserati's manufacturing, engineering, and general assembly project manager.

It also helped Anfosso work out problems before production. This was no small feat. Maserati offers highly customized cars, and the Ghibli comes in 27 versions, 13 colors, and 205 different configurations. The virtual factory Maserati devised had to be flexible enough to create the parts needed for each combination without slowing down.

There was also a second complication: Maserati planned to make the Ghibli at its Grugliasco factory, which already produced Maserati's Quattroporte luxury sedan.

"The challenge," Anfosso said, "was to integrate two new assembly lines into an existing facility."

Maserati designed its factory while still designing its new Ghibli.
Photo: Courtesy of Maserati

To be able to introduce the new models to the market as quickly as possible, engineers laid out the new lines while the Ghibli was still on the drawing board.

"Our design engineers rapidly went through different modification scenarios of the new models over and over again. Accordingly, we had to continuously adjust the production facilities," Anfosso said.

Fortunately, software tools are rapidly rising to the challenge of concurrently building and integrating digital twins. Anfosso's team, for example, used Siemens' Tecnomatix to analyze how car design changes affected production, so they knew where to focus their attention.

As the technology evolves, those tools will grow more powerful and sophisticated, and IoT-enabled digital twins will become more tightly integrated into a plant's production processes, and far more capable.

They will also become smarter, using machine learning programs, a type of artificial intelligence, to learn more about a factory's machines and improve the ability of digital twins to simulate and predict their behavior.

"At the outset, you have a good idea of what operating parameters should be, but you can improve your prediction capabilities by incorporating data as the machine is operating, and learn from that data," Goossens said.

As AI systems learn more about specific machines, they will use their digital twins to help engineers run plants more efficiently. An odd sound coming from a machine? AI can analyze it to see if a screw is loose or a bearing is starting to fail. The better the AI knows the machine, the more accurately it can predict when that failure is likely to happen. And the more options—fix it now, run the machine to maintenance, or readjust production schedules and take the machine offline—it can offer a plant manager.

Digital twins are evolving rapidly. Where will it end up? More economical manufacturing of small lots, or even lots of one? Maybe. Hyper-customized products? Perhaps. Fully programmed and optimized production lines that need only a few hours of shakedown before startup? Hopefully.

Machines managing and controlling other machines? Closer than we think. That is what Siemens is demonstrating in an Industrie 4.0 plant in Amberg, Germany. It churns out 12 million programmable logic controllers (used to automate machinery) each year, and uses extensive digital product and process twins to keep everything on track.

The results are stunning. By using digital instruction manuals and robots to ferry parts from one workstation to the next, it can produce any one of Siemens' extremely broad range of PLCs in just 24 hours.

It takes almost no human intervention. Each day, Amberg's software, machines, logistics robots, and digital twins exchange 50 million discrete communications. These interactions determine which machines manufacture what components, and how each workpiece flows along the factory floor.

They also compare digital twin simulations to physical machine and product data, so the factory can tune and retune its equipment. This achieves remarkable levels of quality: only one out of every 100,000 finished products has a defect—despite churning out hundreds and even thousands of different products every day.

This is very much what mass customization looks like. One day, Orchard said, similar plants may churn out customized products nearly as inexpensively as factories that make mass-produced models.

Digital twins will make that possible, as well as a whole lot more. Their future is still being written. **ME**

JEAN THILMANY is a technology writer based St. Paul, Minn.

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