Digital Twin Technologies for High-Performance Manufacturing
Digital twin technology provides real-time, interactive simulations of work in progress at a manufacturing facility. The technology brings manufacturing and product lifecycle management activities together and transforms the methods teams use to work with products and systems. The benefits are fundamental and can help manufacturers improve innovation, efficiencies, quality, and yield to better position their organizations for success in today's highly competitive markets.
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Introduction

Manufacturing has an important, new opportunity to revolutionize operations and business performance with “digital twin” technologies that can intelligently simulate equipment or products during the development lifecycle. Digital twins provide real-time, interactive, virtual representations of work in progress at a facility, enabling organizations to quickly identify areas for innovation and adjust designs or processes to achieve targeted improvements.

Manufacturers are always looking for techniques to bolster performance outcomes, and digital twin solutions are practical tools that can improve an organization’s operating efficiency, product quality and yield while reducing costs. Digital twins also benefit the workforce because the tools transform the human-machine interface, enabling employees to engage with manufacturing equipment and systems in ways that were not possible before. The conveniences are motivating organizations to reimagine how teams can create and collaborate during design, build and operations activities.

This paper explains the importance of digital twin technologies and highlights use cases for typical facilities. The paper describes the components used in an implementation and suggests steps companies can take to begin using digital twins in their plants.

What is Digital Twin Technology and Why is it Important to Manufacturers?

A digital twin is a virtual representation of a physical entity or system. The digital twin is much more than a picture, blueprint or schematic: It is a dynamic, simulated view of a physical product that is continuously updated throughout the design, build and operation lifecycle. The digital twin and its corresponding physical object exist in parallel, evolving together as the physical product progresses and matures.

A digital twin is a powerful tool for manufacturers because it is informed by sensor data that are collected from the twin’s physical counterpart, fed into an IoT platform and enriched by artificial intelligence. The virtual replication of the object is presented on high-definition, immersive displays that manufacturing teams and business professionals can use to visualize the object’s status and interact with it in real time without disrupting production.

Teams can use a digital twin to modify designs; perform what-if simulations of new design options without building physical prototypes; adjust the manufacturing process; or automate operations and maintenance functions. Different
“Digital twin technology brings manufacturing and product lifecycle management activities together in an organization and opens up opportunities to reimagine how teams interact with designs and equipment,” says Anirban Bhattacharyya, associate partner for digital strategy and cognitive process transformation at IBM. “These are very fundamental benefits that will help manufacturers position for success in today’s highly competitive business environment, which demands that companies find innovative ways to improve efficiencies, quality, and yield while reducing costs.”

Digital Twin in Aerospace Manufacturing

An aerospace and defense supplier used digital twin technology for a PLM initiative to improve manufacturing on one production line and reduce the need to perform maintenance or rework. The project involved designing a product, modeling various design options and revisions, and simulating a production scenario. As a result of the effort, the company was able to improve product quality prior to launch. It also gained a new competitive advantage based on the design and reduced operational costs by 7%.

These exciting capabilities are made possible by cognitive manufacturing, which leverages cognitive computing, the Industrial Internet of Things (IIoT), data science and advanced analytics to help organizations optimize manufacturing processes. Digital twin is a compelling application of cognitive manufacturing because it not only optimizes manufacturing, it dramatically transforms the methods teams use to work with products and systems.

Digital Modeling and Digital Thread: Key Enablers for Digital Twin Solutions

Digital twin solutions are made possible by two key enabling capabilities: digital modeling and digital thread.

Digital Modeling

Digital modeling is used to experiment with a digital twin. Teams can use digital modeling to test or validate new designs represented by a
digital twin; perform what-if analyses of design options; understand the causes and effects of design, build, and operate decisions; and eliminate undesirable approaches. All of this can be done without the need to conduct real-life prototyping. The process makes innovation easier while saving time and reducing costs.

**Digital modeling + data science:** Digital modeling is especially powerful when it employs data science tools to inform the modeling process. The insights gained from data-driven modeling provide distinct benefits that can help companies solve customer problems as well as manufacturing issues. Practical applications address project lifecycle management (PLM), shop floor and asset maintenance activities.

For example, data science-enriched digital modeling can be used with PLM tools to consider insights from suppliers, warranties and customer return programs during the digital design of a product. The approach makes it possible to optimize a product design to ensure there is no gap between product quality and functionality and customer expectations.

During manufacturing, data-enriched simulations—enhanced by cognitive computing insights and predictive analytics—can be used to model and remodel the performance of plant equipment under a variety of what-if scenarios. The technique can help identify the best approaches for improving key performance indicators (KPIs) for the manufacturing process and product quality.

Asset maintenance, part of the operations cycle, is another function that benefits from data-driven modeling. In this context, machine learning, deep learning and artificial intelligence can be applied to dynamic process monitoring and machine health data to better detect anomalies and predict failures. The approaches can transform maintenance into a proactive activity and even enable feedback loops that automate procedures to resolve maintenance issues.

**Digital Thread**

The digital thread is the traceable flow of data that interconnects all relevant systems and functional processes involved in a product’s lifecycle and informs the digital twin and digital modeling activities.

The digital thread is comprehensive and holistic. It facilitates the exchange of real-time data between sensors that are monitoring a physical object and the object’s digital twin; integrates with a company’s IoT platform that transmits information between devices and a digital twin application; includes data from enterprise applications, business operations and management activities; and provides data and context for visualization tools.
Because it is comprehensive, the digital thread yields an end-to-end perspective of issues and problems that might emerge during the manufacturing life cycle. PLM becomes more responsive and agile, enabling a company to produce high-quality products while increasing manufacturing efficiencies. The digital thread also eliminates business or engineering silos because it enables different stakeholder groups to access and use the digital twin and underlying data.

The digital thread uses ISA-95 standards to automate communications between control and enterprise systems. This approach makes implementation easier for manufacturers and facilitates integration with companies that are partners in the digital twin ecosystem.

Three Use Cases: Design, Build, Operate

Digital twin technologies inform and guide continuous engineering practices. The tools help individuals and teams create and refine products at all stages of the product’s lifecycle: design, build, and operate.

**Design—Streamlining projects that have complex requirements and rapid design cycles**

Digital twin technologies revolutionize product design. Teams can explore the impacts of various design alternatives on a product’s performance; use digital modeling to ensure a design meets product or regulatory requirements; and improve the designs as the simulations suggest. The conveniences shorten the development cycle to accelerate time-to-market while also improving the quality of the manufactured product.

Organizations can build digital twin capabilities by establishing a digital thread to interconnect
data from relevant physical components and processes and integrating the thread with a design simulation. Once these capabilities are established, teams can apply “cognitive sensing,” which analyzes the raw data collected from sensors, to continuously update the digital twin. Teams can also generate rules that automate design decisions or actions to facilitate self-healing. Virtual reality or augmented reality can enhance visualization tools to deliver a stimulating, immersive working environment for designers.

Build—Optimizing the manufacturing process to improve quality, efficiency and yield

Manufacturers are always striving to optimize quality, efficiency and yield. Now they can use digital twin technologies to understand how potential changes in the manufacturing process might impact production outcomes and adjust their manufacturing conditions accordingly to achieve targeted improvements.

Digital twin technologies can be introduced to the build process in stages. Organizations can lay the groundwork by putting applicable cognitive sensing and digital thread capabilities in place. Data from the digital thread can be used to continuously monitor the manufacturing process and perform digital modeling of process options. Intelligent visualization tools that have touch-screen UIs, 3D imagery, augmented reality or virtual reality features will enhance digital modeling and associated analyses. Insights derived from these methods can be used to improve product quality and yield or to create manufacturing plans that optimize manufacturing while reducing costs. The solution can also be used to guide coordination with supply chain partners.

Digital Twin in Automotive Manufacturing

A motorcycle manufacturer installed large screens on its shop floors to display digital twins of machines, processes and products that are used for manufacturing or being manufactured at the facility. Teams are using the digital twins to reveal the real-time status of their manufacturing processes, locate production bottlenecks, and identify quality issues. An associated dashboard enables teams to use digital twin data to forecast deliveries and sales and interact with suppliers and distributors. The implementation has helped the manufacturer reduce costs while improving product quality and yield. The application illustrates how companies can use digital twin solutions, in conjunction with suppliers and partners, to improve the manufacturing process and products.
Operate—*Increasing uptime while minimizing maintenance and servicing needs*

“Operate” refers to operation, servicing and maintenance activities. Companies can apply digital twin solutions in these contexts to increase uptime and improve operating efficiencies while making sure equipment and products function at optimum levels.

Digital twin solutions introduce unprecedented conveniences in this use case because the technology enables technicians to “see” inside the virtual representation of a device to identify potential problems. The digital twin can also incorporate information from enterprise asset management (EAM) software and automation programs so technicians have up-to-the-minute information about a machine’s operating status, recent alarms or maintenance activities. The solution can also advise technicians on how to perform maintenance procedures for the problems they’re addressing.

Manufacturers can enable these capabilities by incorporating cognitive sensing into their instrumentation and monitoring systems and establishing a digital thread to integrate the data with their EAM and other applicable software. Once the capabilities are established, teams can use data-enriched digital modeling to troubleshoot problems, perform root cause analyses of equipment failures, predict operational issues, or improve their design and build processes.

**An Integrated Framework for Digital Twin Implementations**

A digital twin implementation uses a framework of technologies that work together as a system of systems to help companies transform and optimize their design, build, and operations processes. Key components include the following:

**Cognitive sensing:** Cognitive sensing employs analytics and machine learning to add intelligence to raw data collected from sensors that monitor physical objects and systems for data and image processing. The sensor-based intelligence is integrated into a digital twin solution via an IoT platform.

**IoT platform:** The IoT platform provides connectivity to sensors and transmits data to or from the devices for use by a digital twin application for analysis and computation. The data become part of the digital thread that interconnects the components in a digital twin architecture.

**Software tools:** Digital twin tools include software used to build the digital twin and perform
digital modeling and manage projects. Tools can include computer-aided design (CAD), computer assisted manufacturing (CAM) and various simulation programs as well as asset lifecycle management (ALM) and product lifecycle management (PLM) programs.

Enterprise applications: The framework makes it possible to use real-time data from enterprise applications to support decision-making on the shop floor and in corporate sales, strategy and operations offices. Typical applications include predictive maintenance tools, enterprise resource planning (ERP) and enterprise asset management (EAM) programs, supply chain management software, manufacturing execution systems (MES), and customer relationship management (CRM) solutions.

Intelligent visualization tools and dashboards: Digital twins feature high-tech displays and visualization tools that enhance the accuracy of product simulations and inspire innovation. Teams can use augmented reality, virtual reality, touch interaction, pinch/zoom and other user interface capabilities to interact with the digital twin. Dashboard views can deliver actionable insights in real time to the screen during any phase of a product’s lifecycle so teams can respond immediately to adjust conditions or solve problems.

An Open Framework Brings Technologies and Partners Together

Because a digital twin accesses data from multiple sources, the underlying framework must be open to accommodate data from the many participants in the solution’s ecosystem. An open framework enables both operational, IT and business teams to work with the digital twin, eliminating information and business silos that have prevented data integration and collaboration in years past. An open ecosystem also facilitates and encourages collaboration with relevant vendors.

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systems to manufacturing companies have important roles in the ecosystem. Their components and solutions must be able to integrate with the applications.

**Connectivity:** A facility needs reliable connectivity to deliver data to and from components in the architecture and the various ecosystem participants. Whether they are using Ethernet cables or a wireless approach such as Wi-Fi or LTE for connectivity, organizations will need sufficient capacity and bandwidth to support real-time access to massive data files and the feature-rich software applications used by their digital twin solutions.

**Approaches for Implementation and Structuring Costs**

Because a digital twin is highly specific to each facility and organization, manufacturers will need to tailor their implementations to serve their particular use cases and business requirements.

Organizations can build digital twins by using APIs to configure and customize the applications and integrate the applications into an IoT platform. Another option is to use turn-key,

The open framework should include the following:

**Applications:** The ecosystem must be able to integrate and exchange data between the IoT platform, sensing engine, the digital twin, digital modeling tools and the digital thread, as well as internal and third-party software, enterprise applications, visualization tools and dashboards. Open APIs are encouraged to facilitate integration.

**Engineering organizations:** Companies that supply equipment, sensors and other critical
as-a-service solutions that streamline hardware and software deployment, systems integration, and ongoing management of the digital twin applications. Companies can use on-premise, cloud, or hybrid infrastructure. The best approach for an implementation will depend on the types of data center resources the manufacturer has available or needs; its budget for capital and operating expenses; the scope and scale of the deployment; the number of vendors participating in the ecosystem; and the organization’s plans to expand its digital twin application in the coming years.

An important advantage of the as-a-service model is the flexibility of fee structures, which helps manufacturers manage and control costs. Manufacturers can choose from a range of pricing options, including freemium models, tiered subscriptions, connection-based or pay-as-you-go consumption models, among others. Fee structures can be modified and adapted, as well, as a manufacturer evolves and expands its deployment.

How to Get Started

Here are some practical tips for applying digital twin technologies in your business:

Selecting a project: Select the projects that will yield value quickly so your organization will realize digital twin benefits as soon as possible. A good way to find the best projects is to identify the manufacturing KPIs or other outcomes you want to achieve and look for opportunities in your plant and processes that will help yield the targeted outcomes. Select projects that span the product lifecycle so the implementation meets the needs of your teams during all phases of design, build and operate activities.

Implementing digital twin: Like many operational and IT projects, digital twin solutions are implemented incrementally. Take these steps to build your solution:

- Obtain the CAD/CAM versions of the machine or product from the team or engineering partner that produced the original design.
- Create a new digital model of the machine that considers the equipment’s mechanics, the machine’s interactions with other equipment in the facility, the product being produced, and relevant operational or enterprise software applications.
- Make sure the physical machine you’re modeling is monitored by sensors and connected to a gateway that integrates with an IoT platform.
- Give special attention to data quality at every stage of design, build and operate.
• Apply cognitive analytics and machine learning to the sensor data (cognitive sensing) to bring real-time context and characteristics to the digital twin.
• Implement a digital thread capability to facilitate information flow between data sources and applications.
• Make sure the solution can generate analytics at every stage of the lifecycle so you can make improvements at each stage of a project and overall.
• Provide displays that enable teams to view and interact with the digital model on the shop floor or from their corporate offices.
• Use an open approach that avoids centralizing data in a proprietary system so your digital twin solution can be used by all stakeholders.
• Conduct a proof of concept project, using one machine or one operation. Once that is in place and working, expand it to an entire manufacturing line.

Promote a digital manufacturing culture: Digital twin is a new concept. While its conveniences and benefits are well recognized, companies will need to educate their employees about the role of digital twins in their facilities and the technology’s value to the organization. Take these steps to underscore your messaging:

• Secure and demonstrate executive support for your digital twin project.
• Explain that digital twin technologies play key roles in cognitive manufacturing.
• Also explain how digital twin technology helps reimagine the workforce. It optimizes collaboration between employees and computerized and automated systems.
• Encourage buy-in and support from employees. Engage operational and corporate teams on implementation planning committees.
• Provide skills and training to make sure employees are ready to use the applications when you launch your digital twin solutions.

Involve your sales organization in your digital twin initiative: Digital twin not only benefits manufacturing team, a company’s sales organization can use the cutting-edge simulations when engaging with business customers and partners to inform and help guide supply chain processes. Incorporate the sales division in your change management strategies to gain their support early. This will help your project gain acceptance and get off to a strong start.
IBM digital twin solutions use IBM cognitive manufacturing technologies and the IBM Watson IoT platform. The company brings extensive field knowledge to all of its engagements. Its digital twin solutions will integrate with a manufacturer’s internal systems and tools as well as equipment supplied by the manufacturer’s engineering partners to provide holistic, end-to-end solutions tailored to specific facility, processes, products, and business needs.

As part of its efforts, IBM is helping the industry create a new data economy for digital twin and other cognitive manufacturing applications. IBM is partnering with organizations to create data-as-a-service capabilities that can be monetized internally and externally to promote adoption and support of data-driven applications and tools.

Digital Twin Technologies and IBM’s Role

IBM digital twin solutions are offered to manufacturers through the IBM GBS Digital Operations & Internet of Things Services, which helps companies transform their operations through business and operating models that are enabled by the IoT and led by analytics to optimize efficiency, customer-centric strategies, economic growth and maximum asset productivity.

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