DIGITAL TWINS—VIRTUAL MODELS OF PEOPLE AND OBJECTS

/// THE TECHNOLOGY

**What is it?** Digital twins are virtual representations of people or physical objects, processes, or systems, ranging from vehicles to industrial plants to clinical trial patients. These “living” computational models integrate with data from a physical twin, such that any changes made to the physical twin can automatically lead to changes in the digital twin (see fig. 1). Digital twins can be used to remotely maintain or monitor the physical twin, or predict how it will perform.

Digital twins can be applied across many fields. For example, they can help more efficiently design aircraft parts, predict and avoid supply chain disruptions, and improve traffic safety. They could also monitor living systems or predict hypothetical effects on them for applications in health care, agricultural management, and climate forecasting.

**How does it work?** Digital twins rely on multiple existing technologies, including the Internet of Things, a network of interconnected “smart” devices that exchange information and collect large amounts of data. Sensors built in or placed on the physical twin or around its environment can collect data continuously. These sensors transmit data that update the digital twin through technologies such as network interfaces and cloud platforms, depending on the physical twin and its location. For example, sensors in a factory may transmit data to a digital twin via local wireless networks, but sensors in public spaces may require cellular networks for adequate connectivity.

Digital twins use these data to dynamically change along with the physical object in real time. This allows users to interact with a 3D visualization, monitor changes, and predict the effect of future events. For example, digital twins of smart cities can be used to predict how extreme weather events will affect the power grid, and what cascading effects might follow. Digital twin data can also be analyzed using artificial intelligence and machine learning to test different scenarios or make predictions for the physical twin. For example, machine learning could automatically recognize an abnormal pattern in a patient’s digital twin, enabling a quicker diagnosis and improved treatment (see fig. 2).

**How mature is it?** Though the term “digital twin” was coined around 2010, NASA engineers originally applied the concept by building physical and computational models of the Apollo 13 mission vehicles on the ground that were adapted to match the vehicles’ changing conditions in space. Today, the use of digital twins is growing, owing to advances in high-performance computing, rapid data analysis, and smart sensors. Applications in industry include improving operations and predicting or mitigating the effects of manufacturing disruptions.

For example, one company builds digital twins of wind turbines to help manufacturers identify potential problems before scaling up production. The U.S. Navy uses digital twins of shipyards to help inform officials of expected project costs. Digital twins are also being used to more efficiently rebuild areas of a Ukrainian city destroyed in the conflict with Russia, enabling officials to forecast reconstruction costs and improve the city’s infrastructure and resources. In the U.S., a digital twin of the Orlando region allows local government, companies, and nonprofits to simulate and visualize the effects of scenarios such as climate change and new transit routes.

Digital twin technology is less mature in the biological sciences, primarily due to the complexities of living systems found in areas such as health care, agricultural management, and the environment. Researchers are studying whether digital twins of people could improve health care by predicting patient response to different therapies in clinical trials or by
Manufacturing and engineering efficiency. Digital twins monitor in real time to help avoid potential problems, optimizing manufacturing and engineering projects and reducing costs.

Improved health care. Digital twins could help facilitate predictive and personalized medicine to improve patient outcomes and reduce some health care costs.

Privacy and ethical issues. Security, bias, and data ownership issues, especially for digital twins applied in health care, can reduce public trust in the technology.

Technical and infrastructure barriers. Digital twins are difficult to scale up for more complex systems, and the current U.S. network infrastructure may not be adequate for expanded use.

Economic costs. Digital twins can be costly to develop, leading to potential inequities in their use.

Standards and regulations. Existing standards and regulations for digital twin implementation may not be adequate to address their use in complex systems, especially biological ones.

What options exist for dealing with ethical or equity issues that digital twins could raise, especially in areas such as health care?

What steps could help mitigate potential security and privacy risks associated with digital twin technology?

How could standards and regulations be further developed for digital twin technology, especially when applied to individuals?

Implement Key Product Development Principles, GAO-22-104513

Artificial Intelligence in Health Care: Benefits and Challenges of Machine Learning Technologies for Medical Diagnostics, GAO-22-104629

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