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Digital Twins—An Important Arrow in the Industrial Competitiveness Quiver

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In the words of Andrew Ng, computer scientist, entrepreneur and co-founder of Coursera: "AI is the new electricity." While that may be true, there are other cutting-edge technologies that have received far less attention but are nonetheless transformational—especially when it comes to industrial competitiveness. One prominent example is *digital twins.*

Whereas digital twins and AI work together, there are clear differences A digital twin is a virtual replica of a physical object, process, or system—such as a jet engine, a supply chain, or even a human organ. While a digital twin serves as the *framework* or the *mirror*, artificial intelligence acts as the *brain* that allows the twin to analyze data, predict the future, and make autonomous decisions

Digital twins are increasingly seen as core infrastructure in Industry 4.0 because it integrates IoT, AI/ML, cloud, and advanced analytics into a unified decision environment. Market studies project the global digital twin market to grow from roughly $21–24 billion in the mid-2020s to around $40–260 billion by 2030–2032, reflecting rapid diffusion across manufacturing, energy, infrastructure, automotive, and healthcare.

Digital twins applications

Applications of digital twins cut across leading industries such as manufacturing, aerospace, healthcare and energy. Firms like GE, Siemens, IBM and Airbus. The German automaker BMW is a prime example. The company first began developing virtual replicas of aspects of its production line in 2014. Before rolling out the drivetrains for its electric vehicles in 2021, BMW had created a fully operational virtual version at its Regensburg, Bavaria, factory. The real-time digital twin can simulate production and scheduling at the factory, down to the work-order level.

Besides the corporate sector, more and more academics are focusing their research on digital twins. The academic literature on digital twins has grown rapidly since the mid-2010s, with contributions from systems engineering, manufacturing, computer science, and management studies. Early work emphasized conceptual definitions and reference architectures, highlighting the role of model-based systems engineering and cyber-physical systems in enabling synchronized virtual–physical pairs.

Recent research has focused on several themes. One is *economics and ROI.* Studies such as NIST's work on the economics of digital twins analyze cost–benefit drivers in manufacturing and validate gains from predictive maintenance, quality improvement, and reduced downtime. Another theme is *business models and value creation.* Management and innovation scholars argue that digital twins are enablers of new service-oriented and circular-economy business models, including performance-based contracts and lifecycle services.

Yet another area of applied research *is standardization and interoperability.* Research in engineering and computer science explores ontologies, data standards, and architectures (e.g., alignment with Digital Twin Consortium definitions) to support cross-platform interoperability and scalable ecosystems. Finally, there are *domain-specific applications*. A large body of applied work covers manufacturing systems, energy grids, smart cities, construction, and healthcare, often reporting case-specific performance improvements and methodological frameworks for model building and validation.

Overall the literature converges on digital twins as a socio-technical innovation that is as much about organizational and business transformation as about models and data. One should also note that when discussing applicability by industry, digital twins is crosscutting and increasingly used in many sectors. The chart below provides a high-level view of leading industries and typical applications.

Industry and Digital Twins Applications

Industry	Typical digital twin applications
Automotive & transportation	Vehicle and powertrain twins, EV battery health, autonomous driving validation, fleet and logistics optimization.
Manufacturing (discrete)	Production-line twins, machine-tool twins, factory and supply-chain twins for scheduling, quality, and predictive maintenance.
Energy and utilities	Power-plant, grid, and pipeline twins for reliability, load balancing, and asset health; wind-farm and renewables optimization.
Construction / AEC / smart infrastructure	Building and campus twins, infrastructure and city-scale twins for planning, operations, and maintenance; integration with Building Information Modeling (BIM).
Healthcare and life sciences	Device and imaging twins, hospital operations twins, early work on patient-specific twins for treatment planning.
Aerospace and defense	Aircraft, engine, and mission-system twins for design, certification, and in-service monitoring.
Real estate and retail	Facility and store twins for layout optimization, energy management, and customer-flow analysis.

Examples and realized benefits of digital twins

Concrete examples abound of the qualitative and quantitative benefits of digital twins across sectors. For example, in industrial manufacturing case studies summarized by industrial analytics vendors and consulting reports show that AI-enabled factory twins can reduce thermal-energy use by up to 40%, cut unplanned downtime significantly, and deliver payback within roughly a year in some plants. These initiatives qualitatively improve cross-functional collaboration, standardize best practices across sites, and support workforce upskilling via simulation environments.

Infrastructure and smart cities is another area where digital twins shines. Analyses of government infrastructure twins suggest potential improvements of 20–30% in capital and operational efficiency for large public investments by enabling better design choices, phasing, and real-time operations optimization. Benefits also include improved accessibility of services and better resilience planning for transport and utility networks. When it comes to building and space management, platform providers such as Matterport highlight building and facility twins used for remote inspections, space-utilization planning, and maintenance, reducing site visits and shortening leasing and fit-out cycles.

Looking at ROI estimates overall, syntheses of industrial and consulting studies report that predictive-maintenance programs powered by digital twins often reduce machine downtime by 30–50% and maintenance costs by 10–40%, while enabling more efficient energy and material use. These translate into multi-million-dollar annual savings for large plants or fleets and support compliance with increasingly stringent ESG metrics.

The relationship of digital twins to U.S. competitiveness

Digital twins intersects with U.S. competitiveness along multiple dimensions--industrial productivity, innovation ecosystems, standards, and geopolitical technology rivalry.

The actual and potential opportunities brought about by digital twins are, indeed, extensive. Widespread deployment of digital twins in U.S. manufacturing, energy, logistics, and infrastructure can raise total factor productivity by reducing downtime, enhancing quality, and extending asset life, reinforcing the country’s strengths in high-value manufacturing and services.

Innovation and platform leadership are other areas of competitive strength. The U.S. hosts many leading cloud, IoT, and analytics providers that supply digital-twin platforms and services, positioning American firms to shape global ecosystems, standards, and de facto architectures.

Finally, strategic industries and national security considerations weigh heavily, as well. Digital twins in aerospace, defense, and critical infrastructure can improve readiness, resilience, and cyber-physical situational awareness supporting broader U.S. security objectives.

When it comes to global competitiveness with regard to digital twins, it is by no means a slam-dunk for the United States. There are, indeed, threats and challenges. European and Asian economies are investing heavily in digital-twin adoption for green industry, automotive, and infrastructure, narrowing capability gaps and potentially eroding U.S. industrial advantages if domestic diffusion lags.

Other challenges are shortages of advanced modeling, data, and OT–IT integration skills. This may constrain adoption in smaller U.S. firms, while a patchwork of standards and governance frameworks could create inefficiencies relative to more coordinated approaches in some competitors.

Then there is cyber risk exposure. As U.S. critical infrastructure and manufacturing become more dependent on digital twins and connected systems, vulnerabilities to cyberattacks with physical consequences become a national-level risk, requiring robust security and resilience strategies.

In sum, digital twins are both a competitiveness lever and a domain of strategic competition, where leadership in platforms, standards, and secure deployment will matter for U.S. economic and security outcomes.

The five-year outlook (2026–2031)

Market and technology forecasts suggest that digital twins will move from advanced pilots toward mainstream infrastructure in leading firms and selected public-sector domains over the next five years. Projections indicate compound annual growth rates on the order of 40–50%, with global market size reaching roughly $20–150 billion by 2030 and strong growth in North America, Europe, and Asia-Pacific.

Several trends are likely to shape this trajectory:

1. *Convergence with AI and immersive technologies.* Twins will increasingly embed AI for autonomous optimization and decision support and will be experienced through VR/MR interfaces, enabling more intuitive human-in-the-loop operations and training.
2. *Expansion beyond single assets.* Organizations will shift from asset-level twins to system-of-systems twins (factories, campuses, supply chains, and cities), requiring more robust interoperability standards and governance frameworks.
3. *Institutionalization and regulation.* As twins become critical to infrastructure, energy, and healthcare, regulators and standards bodies will likely address data governance, safety, cybersecurity, and liability, which could both de-risk and slow certain deployments.

For the United States, the outlook is for digital twins to remain a strategic component of smart industrial and infrastructure policy, with opportunities to deepen leadership if investment in skills, security, and open standards keeps pace with technological and market growth.

There is very little our two main political parties can agree upon today; however, the value of digital twins as a tool of national competitiveness is unquestionably a policy path that garners strong bipartisan support.

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