QuantumBlack
AI by McKinsey

Digital twins: The key to unlocking end-to-end supply chain growth

Complexity, COVID-19, and competition have upended supply chain organizations. They can reignite revenue growth and deepen resilience by deploying AI-powered digital twins.

This article is a collaborative effort by Alberto Oca, Alex Cosmas, Cenk Tunasar, and Ketan Shah, with Lauren O'Neil, representing views from QuantumBlack, AI by McKinsey and McKinsey's Operations Practice.

November 2024

The post-COVID-19 era has created lasting fissures in the supply chain. Amid increasing globalization, rising customer expectations, and double-digit shipping growth,[1] supply chain organizations—not just manufacturers and suppliers but also the warehouses and transporters they rely on—are under duress. They grapple with issues related to operational efficiency, demand forecasting, inventory management, and fulfillment. This complexity affects every part of the supply chain in every industry: retail, technology, automotive, industrial, food services, telecommunications, and more. The result is stalled growth and missed revenue opportunities.

Several competing forces are exerting pressure on the supply chain: consumer demand for low-priced products delivered via fast-and-free shipping; rising wages for manufacturing, warehouse, and delivery employees; and murky visibility into future macroeconomic disruptions. McKinsey research shows that more than 90 percent of US consumers now expect two- to three-day delivery for purchases and one-third expect same-day delivery.[2] And ever since the pandemic disrupted in-person sales, B2B companies expect their suppliers to offer omnichannel sales via online marketplaces, mobile, videoconferencing, and chat.[3]

Fulfilling these expectations is more challenging than ever. High labor prices—including a more than 30 percent increase in warehousing wages between July 2020 and July 2024[4]—make it difficult to maintain low prices while meeting margins. Manufacturing labor shortages undermine the ability to create steady inventory flows, while unexpected economic shocks such as recent inflation complicate demand forecasting. And even when the supply side is functioning well, fulfillment remains a challenge; warehouse storage rates remain constrained, causing products to reach recipients late.

Digital twins could heal the supply chain

Under these circumstances, organizations that do not recalibrate their supply chain operations risk falling behind. Digital twins can help with that recalibration. Leading companies are already turning to them to ensure their supply chains are flexible, agile, and responsive enough to overcome unexpected disruptions.

Digital twins are virtual replicas of an object, system, or process used to simulate potential situations and outcomes. Digital twins use real data (sometimes in masked or synthetic forms) to deliver analytical insights and visualizations. Many organizations use digital twins to optimize operations, plan scenarios, and aid decision making. Market analysis indicates the global market for digital twins will grow about 30 to 40 percent annually in the next few years, reaching $125 billion to $150 billion by 2032.[5]

Digital twins can be used to model the interaction between physical and digital processes all along the supply chain—from product ideation and manufacturing to warehousing and distribution, from in-store or online purchases to shipping and returns. Thus, digital twins paint a clear picture of an optimal end-to-end supply chain process. What's more, paired with today's advances in predictive AI, digital twins can become both predictive and prescriptive. They can predict future scenarios to suggest areas for improvement or growth, ultimately leading to a self-monitoring and self-healing supply chain. In other words, digital twins empower the switch from heuristic-based supply chain management to dynamic and granular optimization, providing a 360-degree view of value and performance leakage.

To understand how a self-healing supply chain might work in practice, let's look at one example: using digital twins, a retailer sets dynamic SKU-level safety stock targets for each fulfillment center that dynamically evolve with localized

[1] "Air Cargo Market Analysis," International Air Transport Association, March 2024.
[2] *Retail speaks: Seven imperatives for the industry*, McKinsey and the Retail Industry Leaders Association, March 10, 2021.
[3] "B2B sales: Omnichannel everywhere, every time," McKinsey, December 15, 2021.
[4] "Employment statistics," US Bureau of Labor Statistics, July 2024.
[5] Average growth calculated from digital twin market reports from Roots Analysis (41 percent CAGR for 2024–32 to reach $150 billion in 2032), December 2023; and GMI Insights (33 percent CAGR for 2024–32 to reach $125 billion in 2032), March 2024.

and seasonal demand patterns. Moreover, this granular optimization is applied not just to inventory management but also to every part of the end-to-end supply chain—from procurement and product design to manufacturing and demand forecasting. For example, the retailer's granular production planning could be done in coordination with downstream transportation decisions and inventory positioning. Dynamic planning might identify, for instance, a high-volume commodity item with cross-sell potential, where higher manufacturing costs for the item are offset by lower end-to-end logistics costs through bundled shipping and higher customer conversion. This type of complex predictive modeling is what digital twins do best. Typical results in such a scenario are up to a 20 percent improvement in fulfilling consumer promise (achieving the delivery date communicated to the consumer), a 10 percent reduction in labor costs, and a 5 percent revenue uplift.

Digital twins optimize today's SCM software

Today's supply chain management (SCM) software—which includes a range of products, such as advanced planning and scheduling (APS) tools, warehouse management systems (WMS), and transportation management systems (TMS)—has automated large parts of the supply chain in the past decade, dramatically streamlining how suppliers, buyers, and shippers intersect.

Digital twins can integrate with existing SCM tools, functioning as an innovation layer that sits on top of the tech stack. In this manner, digital twins can optimize data inputs into SCM tools, generating predictive analytics to address and respond to multiple potential scenarios. For example, a global OEM created a digital twin to optimize the policies it fed into its TMS platform for outbound logistics. As a result, the OEM reduced costs for freight and damages by 8 percent.

Digital twins help augment SCM tools in several ways:

— *End-to-end connections:* Digital twins can connect SCM tools throughout the supply chain to provide an integrated view of performance and up- and downstream decision impacts. This eliminates a siloed approach in which each tool only optimizes its local variables, with little coordination among them. For example, one retailer used digital twins to connect their planning, inventory deployment, and transportation management tools.

— *Resiliency in dynamic markets:* As volatility continues to increase post-COVID-19, supply chain operators must continually update their policies due to both fluctuating demand and intermittent supply shocks, such as port disruptions or availability of materials. When combined with digital twins, SCM tools provide real-time visibility into granular performance, paired with predictive and prescriptive analytics to dynamically identify risks and recommend policy changes for rapid resolution. For example, one OEM used automated sense-and-respond digital-twin capabilities to identify shifts in carrier performance and surcharges, effectively reducing last-mile transportation costs by 5 percent.

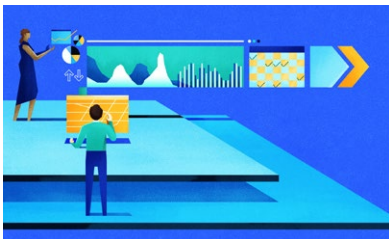
— *Multiple objectives:* Digital twins can optimize across competing priorities and complex constraints for rapid response to market changes. For example, one automotive OEM used digital twins to dynamically shape demand based on shifting supply availability and operational complexity, collectively solving across both sales and operational objectives.

— *Variability:* Digital twins combined with SCM tools can test for a distribution of potential scenarios by analyzing metrics, such as lead time, demand, and supplier reliability, while also considering what-if outcomes. For instance, a consumer-packaged-goods company measured variable demand and labor in its warehouse and identified the opportunity to reduce total distribution center costs by 15 percent. This exemplifies network resiliency.

A deep dive into digital twins

Seeing digital twins in action is the best way to understand how they can deliver value at key points in the supply chain. Explore the below potential use cases to see how digital twins can solve real pain points throughout the supply chain to improve efficiency and resiliency.

Forecasting and demand planning



Predicting demand

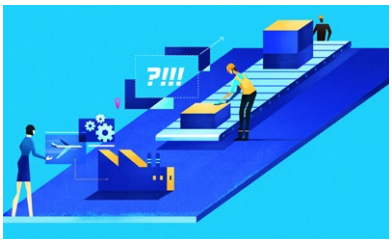
Pain points

- Inaccurate forecasting leads to excess inventory/stock-outs and nonoptimal cost structures
- Lack of real-time data impedes response to market changes

Digital-twin use cases

- Probabilistic demand forecasts and what-if analysis
- Scenario testing and dynamic, SKU-level upstream demand planning
- Dynamic prioritization, especially when supply is constrained

Sourcing and production planning



Optimizing supply

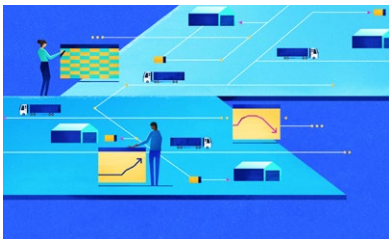
Pain points

- Lack of visibility into sourcing and suppliers
- Production downtime or insufficient production capacity

Digital-twin use cases

- Global production planning optimized for end-to-end inventory flow
- Production plans that balance trade-offs in production costs, logistics spend, and customer experience
- Real-time and predictive view of supplier reliability

Distribution center network



Network design

Pain points

- Network design reevaluated every five to ten years with new models (for example, models are “one and done”)
- Difficulty planning for unknown supply and demand scenarios

Digital-twin use cases

- Bottom-up model that represents all network complexities and interdependencies
- Evergreen model connected to real-time data sources for optimized network design and inventory management

Distribution center network (continued)

Inventory management and positioning

Pain points

- Inventory levels that do not match demand (for example, stockouts or high inventory levels)
- Elevated middle- and last-mile transportation costs
- Extended customer lead time

Digital-twin use cases

- Granular view of inventory across network, orders, and operational constraints (for example, cold storage)
- Rapid dynamic optimization of policies (for example, safety stock) based on real-time supply and demand
- Cold chain network design to support new products

Warehouse optimization

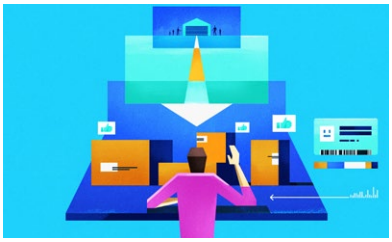
Pain points

- Operational inefficiencies (for example, unclear needs for cold chain storage in the distribution center [DC])
- Only solving for averages, leading to under- and overstaffing

Digital-twin use cases

- Granular view into DC processes to identify inefficiencies and test process changes (for example, maximally efficient cold chain storage in DC)
- Solving for variable demand and interaction with network decisions, given DC inventory visibility

End customers



Fulfillment

Pain points

- Delivery issues (for example, late deliveries, product shortages)
- High last-mile transportation costs

Digital-twin use cases

- Visibility into probabilistic trade-offs to ensure highest service levels at optimal costs
- Optimizing transport with visibility into granular constraints

Reverse logistics

Pain points

- High cost to serve (for example, manual processes to validate feasibility for resale)
- Lack of visibility into available inventory in the reverse-logistics network

Digital-twin use cases

- Bottom-up simulation to test new reverse logistics flow pattern
- Streamlining capabilities across stores and DC networks

Understanding the benefits of digital twins

Supply chain organizations are leveraging digital twins to optimize both their long-term strategies and everyday operations. The most common ways we have seen supply chain companies deploy digital twins are for inventory positioning and forecasting, to manage the flow of goods within the four walls of warehouses and factories, and to aid in production planning. But these are just a few of the ways digital twins are being implemented throughout the supply chain. No matter how digital twins are used, the benefits are clear:

— *Strategic:* Digital twins can derisk long-term planning and broader digital transformations by simulating potential outcomes. This kind of what-if predictive modeling gives companies confidence in the end-to-end impact of their strategic plans. For example, a retailer used a granular digital twin of its distribution network to test the bottom-up implications of a new design for its distribution center. The company had previously used top-down analysis to determine the size and location of a potential new cross-dock. But when teams used a digital twin to model all the potential constraints of that cross-dock placement, they found they could resize and relocate it on 50 percent less real estate without compromising functionality.

— *Operational:* Beyond informing one-time strategy decisions, digital twins can function as "one model to rule them all," optimizing daily decisioning across different operations. In other words, rather than a system of disjointed predictive models, a digital twin can combine many models for integrated forecasting and decision making—dynamically comparing competing trade-offs across the supply chain to suggest granular operational changes. For example, the same retailer used its digital twin to not only optimize its cross-dock footprint in its distribution center but also to optimize its daily inventory positioning decisions—forecasting weekly days-of-supply policies to balance cost, service levels, and sustainability. The result was a 10 percent improvement in regional distribution center utilization and 5 percent reduction in fulfillment costs.

Getting started with digital twins

While supply chain organizations recognize the value digital twins can provide, few have implemented them at scale. Unlike many SCM solutions that are plug and play, digital twins may require a customized build to implement. Because digital twins routinely ingest large quantities of proprietary, masked, or synthetic data, they are almost always custom-built, which takes considerable time and investment. Supply chain organizations must have in-house data science and development teams capable of building digital twins that use advanced AI algorithms, or partner with outside vendors expert in these areas.

Organizations that aspire to embark on the digital-twin journey should focus on five key tenets for success:

— *North Star road map:* Determine the vision for a future supply chain operation built on data and technology. Identify end-to-end use cases that support the North Star vision and then build a road map of use cases by prioritizing for impact—profit and loss or delivery—and feasibility. Typically, companies first prioritize use cases with quick speed-to-impact to prove value early in the journey.

— *Data visibility:* For each use case in the end-to-end road map, identify the data inputs and outputs needed. Build a complementary road map for the organization's data products that supports the use case road map, prioritizing data elements that will be shared across multiple high-impact implementations. Develop these data products iteratively with agile development. To get started, digital twins require a semiregular pipeline of digitized and standardized data, but it's possible to fill data gaps with more static sources such as, for example, average throughput in a warehouse versus daily staffing levels.

— *Technology architecture:* Digital-twin architecture is largely composed of existing data sources and technology, stitched together via APIs and middleware. Typically, a marginal increase in compute capacity is required to support a twin, so ensure that tech teams

have the flexibility to scale current compute resources as needed.

— *Talent:* Assess the skill levels of team members needed to deliver digital twins, including product managers, data engineers, data scientists, user interface/user experience designers, and full-stack developers. Digital twins are most effectively delivered with agile methodologies for rapid development cycles, so product managers may require agile upskilling and training.

— *Optimization and simulation:* Identify the company's first digital twin use case and deploy it. Build on the data products to create optimization and simulation modules that capture use case impact. Then, iteratively expand use cases and combine modules for integrated simulations and end-to-end optimization. Note that teams can start developing simulation and optimization modules before the data product is complete to capture early impact and then integrate these modules later.

End-to-end supply chain optimization requires more than just implementing technology; it also requires a mindset shift at the leadership level and throughout the organization. Internally, companies that use digital twins must endeavor to eliminate internal silos and replace piecemeal institutional knowledge with data-driven decisioning. Externally, companies should carefully analyze their roles in the interconnected global supply chain. In an increasingly complex and interconnected world, organizations across the supply chain can use digital twins to predict potential disruptions and what-if scenarios that could affect their businesses. No one can predict the next pandemic, war, or economic shock with certainty, but digital twins can help companies react and adapt to these eventualities.

Alberto Oca is a partner in McKinsey's Atlanta office, where **Lauren O'Neil** is an associate partner; **Alex Cosmas** is a partner in the New York office; **Cenk Tunasar** is a partner in the Boston office; and **Ketan Shah** is a partner in the Chicago office.

This article was edited by Kristi Essick, an executive editor in the Bay Area office.

Designed by McKinsey Global Publishing