Managing supply chains in times of uncertainty: The emergence of digital twin technologies

While digital twin technology for managing end-to-end supply chains is still in its infancy, many recognize the need, and many companies are leading the way with ambitious pilots.

Emel Aktas and Sharath Bobba · March 19, 2025 ·

The increased vulnerability of global supply chains is everywhere: uncertainty caused by escalating geopolitical tensions, tariffs, more frequent negative impacts of climate change, and, of course, our failure to respond effectively to major demand and supply shocks.

Current supply chain planning and execution processes are disjointed and often too slow to respond. What we need are technologies that can respond holistically to real-time events that are happening today rather than relying on forecast-driven planning based on history. Further, our current planning systems, typically S&OP/IBP processes, are often running at the wrong clock speed to handle today's issues. We need the ability to respond to events in real-time, and have intelligent and autonomous decision-making so we can replan across entire ecosystems at a moment's notice.

Recent advances in artificial intelligence, graph database technology, graph neural networks, and IoT connectivity have resulted in new uses and momentum for the powerful concept of the Digital Supply Chain Twin (DSCT). DSCTs are on the verge of breaking out and proving to provide significant value to solve end-to-end (E2E) supply chain problems.

Until now, digital twins have been hugely beneficial for industrial and medical applications but have typically been limited to single operational contexts, for example, a manufacturing plant or in specific applications such as rapid prototyping for the design of new products. Their uses can be expanded beyond a single plant and product into becoming a virtual "live" representation of facilities, networks, and entire ecosystems. This allows the possibility to

What is a digital supply chain twin?

Interestingly, digital twins for end-to-end systems are not a new phenomenon, and early examples include the use of a digital replica of the Apollo spacecraft on Earth to concurrently simulate events happening in space. It was widely accepted that this capability was instrumental in the eventual safe return of the stricken Apollo 13 mission by simulating events on Earth before sending revised flight plan instructions to the astronauts. Succinctly, digital twin technology involves creating a virtual replica of a physical object, system, or process. This digital counterpart is continuously updated with real-time data, allowing for detailed simulations, performance analysis, and event management.

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A Digital Supply Chain Twin is a real-time virtual replica of a complex supply network. It dynamically models key nodes across the supply chain—including suppliers, factories, warehouses, and customers—while also extending visibility deep into their interconnected networks (customers of customers and suppliers of suppliers).

Each node type has a generic set of associated capabilities and can be configured for each operation in the supply chain and connected to any other node in any direction (toward upstream or downstream). This information provides the basis for the network configuration.

It is this combination of the network coupled with real-time operational data exchange that provides deep insights into supply chain performance and makes it a powerful tool for improving efficiency, analytics, and decision-making.

An example of analytics in the digital twin is the constant monitoring of actual lead-time performance, comparing it to planning master data, and alerting or recalibrating as deviations become apparent. An example of scenario planning is stress-testing the supply network by simulating cost changes, capacity changes, or removal of nodes. Network intelligence can show that the fastest route is highly unreliable and costly due to customs or other delays at certain nodes and so rerouting is preferable.

digital twin

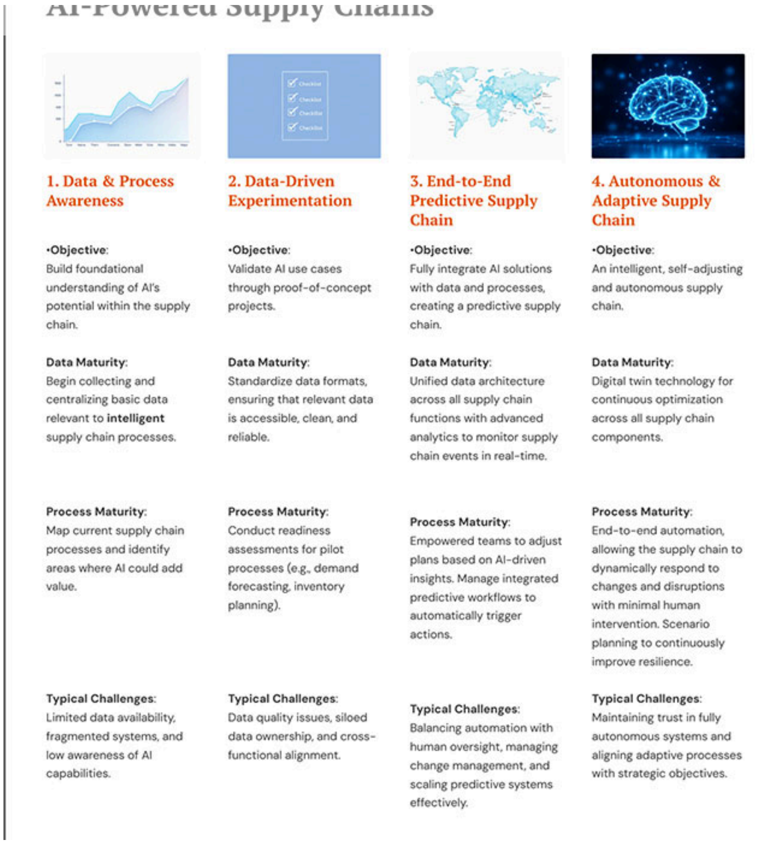
Ecosystem orchestration, simulation, and event response. As supply chains evolve, ecosystem orchestration becomes vital, requiring stronger collaboration with external partners within a connected network. Synchronizing decision-making across functions and enterprises is essential for enhancing efficiency, increasing visibility and reducing costs, resulting in a more resilient and agile supply chain. Companies can now design their supply chains to respond to events as they occur anywhere in the ecosystem rather than only during scheduled planning cycles or when internal operations are impacted. For example, when a supplier is forced offline for two weeks by an unexpected event, the impact can be simulated at the press of a button and contingency plans initiated. Typical supply chain resilience metrics tracked in a DSCT in this instance are Time-To-Recover and Time-To-Survive. These two metrics show how long it will take for the supply network to recover from the disruption (TTR) and how long the supply chain can operate without feeling the impact of the disruption (TTS) owing to decisions on inventory locations and quantities. Another example could be given in terms of analyzing the cost impact of changes. When a supplier increases costs by 20%, this can be factored into the digital twin and the impact on alternative sourcing and margins can be immediately simulated.

Flexibility and structure for advanced analytics and artificial intelligence. Digital twin data structures are infinitely flexible for seamlessly adapting and evolving with supply chain ecosystems. While the network map adapts dynamically; transactional data, analytics, and algorithms remain highly structured to combine the best of both worlds: flexibility to represent real-world networks combined with structure for data integration, analytics, and artificial intelligence.

Additionally, Graph Neural Networks (GNNs) are emerging as advanced machine learning models ideal for analyzing network-oriented data in supply chains. They excel at uncovering intricate patterns and connections, enabling companies to identify trends, predict disruptions, optimize logistics, and recommend actions thus shifting supply chain management from reactive to proactive.

As supply chain executives face the challenge of turning data into actionable insights, advanced analytics, artificial intelligence, and autonomous decision-making are essential for resilient supply chains.

Maturity model for digital twin technology. It is unlikely that companies will transition to a fully functional digital supply chain twins overnight and capabilities will increase over time. We suggest that there are four stages to full maturity across data and processes, as shown in the diagram below.



1. Data & Process Awareness	2. Data-Driven Experimentation	3. End-to-End Predictive Supply Chain	4. Autonomous & Adaptive Supply Chain
•Objective: Build foundational understanding of AI's potential within the supply chain.	•Objective: Validate AI use cases through proof-of-concept projects.	•Objective: Fully integrate AI solutions with data and processes, creating a predictive supply chain.	•Objective: An intelligent, self-adjusting and autonomous supply chain.
Data Maturity: Begin collecting and centralizing basic data relevant to **intelligent** supply chain processes.	Data Maturity: Standardize data formats, ensuring that relevant data is accessible, clean, and reliable.	Data Maturity: Unified data architecture across all supply chain functions with advanced analytics to monitor supply chain events in real-time.	Data Maturity: Digital twin technology for continuous optimization across all supply chain components.
Process Maturity: Map current supply chain processes and identify areas where AI could add value.	Process Maturity: Conduct readiness assessments for pilot processes (e.g., demand forecasting, inventory planning).	Process Maturity: Empowered teams to adjust plans based on AI-driven insights. Manage integrated predictive workflows to automatically trigger actions.	Process Maturity: End-to-end automation, allowing the supply chain to dynamically respond to changes and disruptions with minimal human intervention. Scenario planning to continuously improve resilience.
Typical Challenges: Limited data availability, fragmented systems, and low awareness of AI capabilities.	Typical Challenges: Data quality issues, siloed data ownership, and cross-functional alignment.	Typical Challenges: Balancing automation with human oversight, managing change management, and scaling predictive systems effectively.	Typical Challenges: Maintaining trust in fully autonomous systems and aligning adaptive processes with strategic objectives.

(Photo: Authors)

While digital twin technology for managing end-to-end supply chains is still in its infancy, many commentators recognize the need, and many companies are leading the way with ambitious pilots. It is evident that we are at the beginning of a new era of supply chain technology, and early adopters are likely to benefit from having improved service levels, lower inventory, and more resilient and productive supply chain operations.

About the authors

Emel Aktas is a professor of supply chain analytics at Cranfield University. She is an expert in supply chain analytics, using mathematical modelling for decision analysis in transport, retail, and manufacturing sectors. Her research agenda is to facilitate the use of rapidly growing enterprise and external data with supply chain analytics tools to improve efficiency of operations and decision making for businesses to remain competitive, and a co-founder of Clearpepper, Inc.

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(Photo: Getty Images)

While digital twin technology for managing end-to-end supply chains is still in its infancy, many recognize the need, and many companies are leading the way with ambitious pilots.

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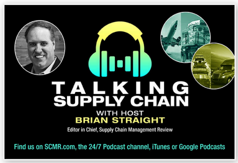

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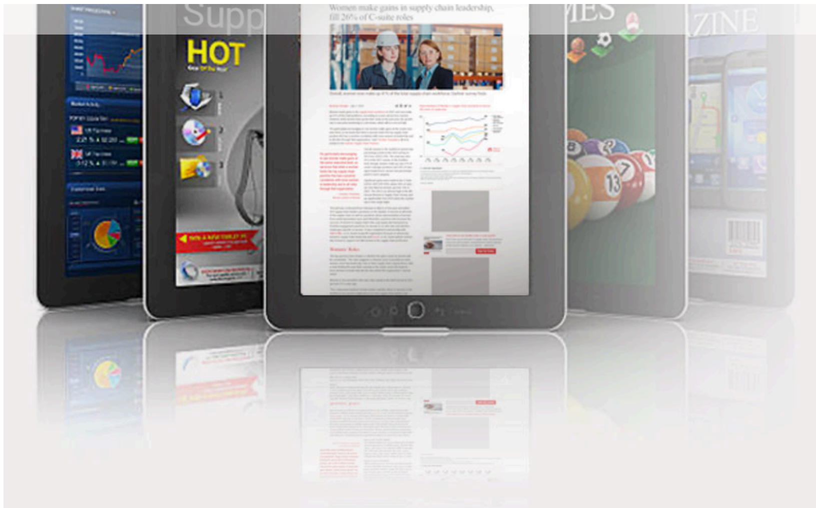

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