Markets, Globalization & Development Review

Volume 9 | Number 1 Article 4

2024

Digital Twinning for Resilient Global Supply chains: Three Case Studies

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Recommended Citation

Yun, Gawon; Hales, Douglas N.; and Hong, Leo (2024) "Digital Twinning for Resilient Global Supply chains: Three Case Studies," *Markets, Globalization & Development Review*: Vol. 9: No. 1, Article 4.
DOI: 10.23860/MGDR-2024-09-01-04
Available at: https://digitalcommons.uri.edu/mgdr/vol9/iss1/4

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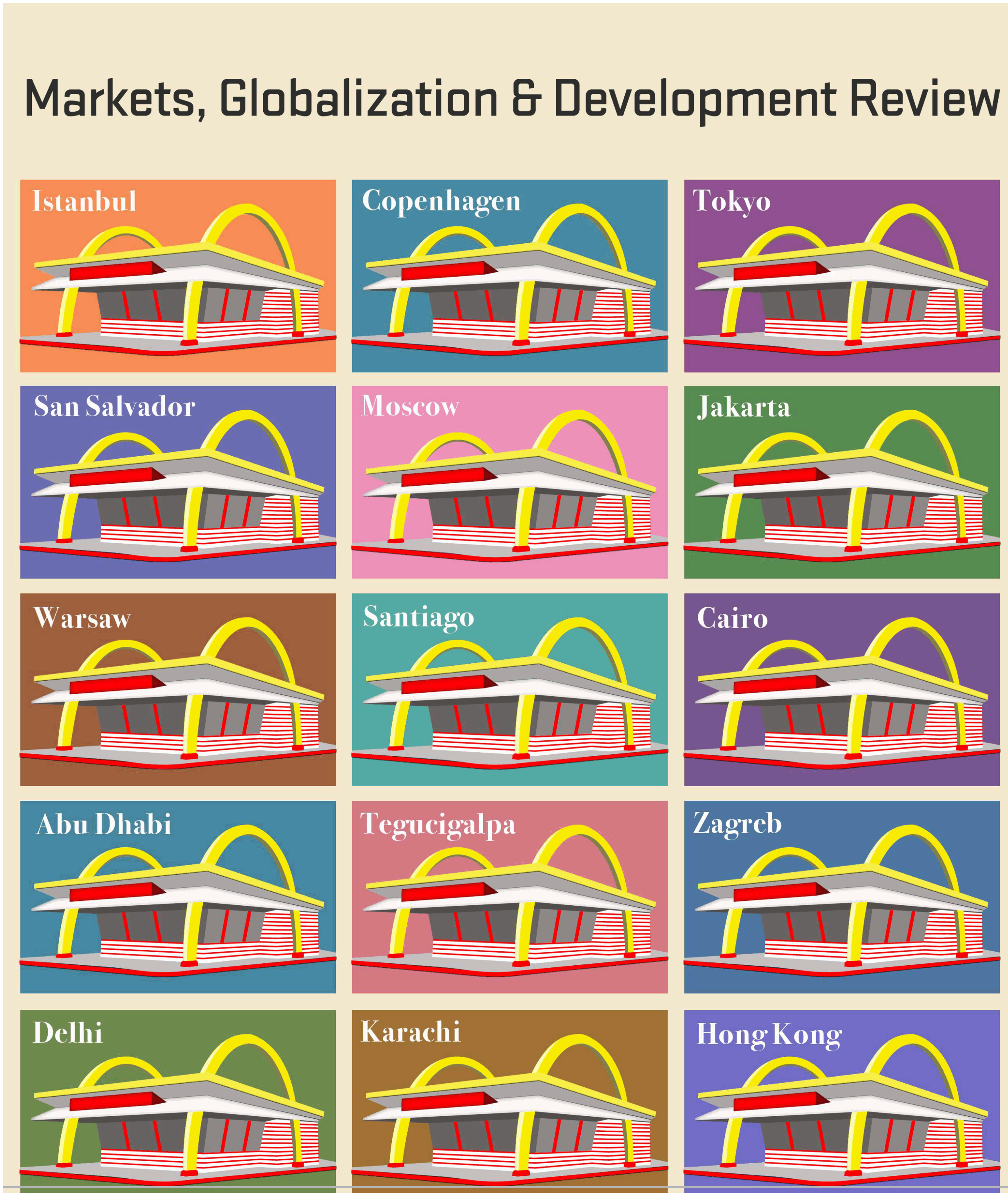
Cover Page Footnote

The authors acknowledge the rapid review and style help provided by the MGDR editorial team.



Digital Twinning for Resilient Global Supply Chains: Three Case Studies

Introduction

Digital Twinning (DT) is a technology that facilitates an exact replica representation of a real process, asset, or network; the data for the simulation are obtained from real-time, onsite sensors (Jones et al. 2020; National Academies 2024). The real setting could be physical, such as a port, transportation network, or manufacturing process, or intangible, such as the behavior of a customer in a marketing campaign or a delivery driver negotiating routes in a city (Dholakia and Hales 2024). DT can provide quick alerts to possible problems and enable early interventions and solutions. In today's global setting, with supply chains highly vulnerable to events such as pandemics and wars, DT can provide early warnings as well as anticipatory actions to counter threats (see Lemos et al. 2020).

The concept of Digital Twins has emerged as a transformative tool in modern industries. In this Dialogue piece, we explore how three companies are leveraging Digital Twins (DTs) to optimize their operations, to reduce costs, and to drive innovation. The companies have requested anonymity. We will thus call the trucking company Lorry-Planet, our global public transportation firm will be referred to as Glob-South-Net, and our electronics firm will go by the pseudonym Eurasia-E-Net. All tried DT and found that DT improved performance on most key indicators. The success was achieved, however, with investment in time and dollar resources at levels that were unacceptable. The challenge remains, therefore, of making DT technologies less costly and faster to implement.

Digital Twins: A Brief Review

Digital Twins (DTs) are representations of real systems, assets, processes, technologies, etc. that are digital in nature and reside exclusively on computer platforms (Jones et al., 2020). Due to the rising costs of testing ideas on real-world systems, DTs are essential to the design, management, and improvement of these systems. The data used to create these exact replicas is collected from sensors, IoT (Internet-of-Things) devices (see, e.g., Lemos et al. 2020), cameras, and even manual inputs. The newer software designed to create and operate DTs includes AWS from Amazon (aws.amazon.com) and Azure from Microsoft (azure.microsoft.com). Based on our experience, these are the two most commonly used platforms in operation today. They are able to collect and input data into the DT using a myriad of information protocols and languages. In addition, they have the built-in capability to display the information in visual formats that appeal to even non-technical users (Jones et al. 2020). There is a paucity of academic research on the use of DTs in industry, and even more so in published case studies. Case studies answer the “How” and “Why” questions in research and are beneficial to practicing managers in understanding the strengths and weaknesses of new technologies. Case studies also lay the groundwork for in-depth scholarly work. Here, we examine how three companies implemented DTs and the strengths and weaknesses of the technology.

Our Approach

To conduct these case studies, we negotiated to collect data from three companies that have implemented and used DTs to improve their operating performance. At least one researcher acted as an independent observer in each company under study. Care was taken not to interfere with the workers who were implementing the technology, and where possible, observations were collected through rooms not directly on the facility workspace or production floor. Each researcher kept a research log documenting the observations and then met with the frontline supervisors after each shift to review and reflect on the observations as well as correct discrepancies in what was observed and what needed further explanation, usually around technical terms. Overall, 20 pages of notes and photographs were collected in each company, with follow-up meetings each day. Observations were completed weekly for four weeks in the beginning, with monthly follow-up meetings for three years until the DT implementations were completed.

The case studies concluded in March 2024 and then were documented as condensed written accounts. These observations were presented to workers and managers to review for accuracy, and multiple revisions were made before final approval to publish and use the results under conditions of corporate anonymity.

Lorry-Planet: A Trucking Company

Lorry-Planet is a leading logistics provider in the trucking industry. Faced with rising fuel costs, stringent emissions regulations, and the need to ensure the safety of its fleet, Lorry-Planet turned to Digital Twins to streamline operations. The trucking industry operates with tight margins, has high capital expenditures, and manages complex logistics. These make trucking firms good candidates for the use of Digital Twin technology.

DOI: 10.23860/MGDR-2024-09-01-04

Before the implementation of Digital Twins (DTs), Lorry Planet faced several challenges, including the following:

- Fleet Maintenance: With hundreds of trucks in operation across vast geographical regions, maintaining a consistent schedule for inspections and repairs was difficult.
- Fuel Efficiency: Rising fuel prices made it critical for the company to optimize fuel consumption across its fleet.
- Driver Safety: Lorry-Planet sought to improve driver safety, reduce accidents, and ensure compliance with federal regulations regarding hours of service and vehicle maintenance.
- Operational Downtime: Unscheduled downtime caused by mechanical failures and road accidents often leads to missed delivery deadlines, increased costs, and customer dissatisfaction.

To address these challenges, Lorry-Planet implemented Digital Twin technology across its fleet. The core components of its Digital Twin solution included the following:

1. Vehicle Digital Twins: Each truck in the fleet was outfitted with IoT sensors, creating a real-time digital replica of the physical vehicle. These sensors provided live data on key parameters such as engine performance, fuel consumption, tire pressure, and brake efficiency. The Digital Twin continuously monitored these factors and used predictive analytics to alert the company when maintenance was required, minimizing the risk of unexpected breakdowns.
2. Driver Behavior Analytics: Lorry-Planet used Digital Twins to track driver behavior in real-time, focusing on parameters like speed, braking, acceleration, and adherence to road safety protocols. This information allowed the company to proactively address unsafe driving habits, reducing accidents and wear-and-tear on vehicles.
3. Fuel Optimization: Using real-time data from the Digital Twins, Lorry-Planet developed advanced algorithms to calculate optimal driving speeds, routes, and load balancing techniques, leading to significant fuel savings. This system also factored in external conditions such as weather patterns and traffic congestion, ensuring the most efficient use of fuel across the fleet.
4. Predictive Maintenance: One of the biggest advantages of Digital Twins for Lorry-Planet was its predictive maintenance capability. The Digital Twin system was able to predict potential mechanical failures before they occurred by analyzing real-time data trends. This allowed the company to schedule repairs during off-peak times, reducing both vehicle downtime and repair costs.

Since implementing Digital Twins, Lorry-Planet has experienced a 20% reduction in maintenance costs. Predictive maintenance has significantly reduced unscheduled repairs and extended the life of its vehicles. There has been a 15% Improvement in fuel efficiency. Optimized routes and real-time adjustments to driving habits have resulted in lower fuel consumption across the fleet. DT has led to improved driver safety, and the real-time monitoring of driver behavior has led to fewer accidents and enhanced compliance with safety regulations. At Lorry-Planet, DT has also minimized operational downtime. The ability to predict mechanical issues has reduced downtime by 25%, improving on-time delivery performance and boosting customer satisfaction.

Overall, the use of Digital Twins at Lorry-Planet has fundamentally improved its fleet management, allowing it to stay competitive in a demanding and cost-sensitive industry, and contributed to sustainability goals. By leveraging real-time data and predictive analytics, the company has optimized both vehicle performance and operational efficiency, positioning itself as an industry leader in innovation and sustainability.

Glob-South-Net: Large Public Transport Operator

Glob-South-Net is a multinational firm that operates large-scale public transportation networks. These include buses, trams, and subway systems. With millions of daily passengers, ensuring operational efficiency and minimizing delays are critical to the company’s success. Glob-South-Net turned to Digital Twins to enhance service reliability, manage infrastructure maintenance, and improve customer satisfaction.

Before the implementation of Digital Twins, Glob-South-Net faced many challenges, such as infrastructure maintenance, service delays, problems in achieving energy efficiency, and enhancing passenger safety and comfort. Glob-South-Net struggled to maintain its aging infrastructure, leading to frequent service disruptions and safety concerns. Delays in public transportation caused by breakdowns and inefficient scheduling significantly affected customer experience and revenue. For Glob-South-Net, reducing the carbon footprint of its operations was a priority, but energy consumption across its fleet of vehicles remained high. Ensuring passenger safety and comfort was a constant challenge, with vehicle overcrowding, unpredictable delays, and occasional breakdowns affecting the quality of service.

To overcome these challenges, Glob-South-Net implemented Digital Twins to create real-time virtual models of its transportation network, encompassing vehicles, infrastructure, and operations. To improve vehicle health monitoring, each bus, tram, and subway car was outfitted with sensors that continuously monitored key mechanical components such as engines, brakes, and HVAC systems. Digital Twins provided real-time feedback on vehicle health, predicting maintenance needs, and minimizing the risk of breakdowns. Additionally, Digital Twins of the company's infrastructure – tracks, bridges, stations, and more – allowed Glob-South-Net to monitor the structural integrity of these assets. Sensors embedded in the infrastructure provided real-time data on stress levels, vibrations, and material degradation. This enabled predictive maintenance of critical infrastructure, reducing the likelihood of catastrophic failures and service disruptions. DTs also facilitated optimized scheduling and routing. Via DTs of the entire transportation network, Glob-South-Net was able to simulate various scenarios, such as changes in passenger demand or adverse weather conditions. These simulations helped the company optimize vehicle deployment, adjust schedules in real time, and reduce overcrowding during peak hours. Finally, Digital Twins also played a key role in improving the energy efficiency of the company's fleet. Real-time data from vehicles allowed the company to adjust driving patterns, optimize braking, and reduce idling times. This led to a significant reduction in energy consumption and a smaller carbon footprint.

Overall, the adoption of Digital Twins at Glob-South-Net resulted in a 25% reduction in infrastructure downtime. Predictive maintenance of tracks and stations reduced the number of service disruptions, improving the reliability of the transportation network. There was also a 20% Increase in on-time performance. Optimized scheduling and real-time monitoring allowed the company to better manage delays and improve overall service punctuality. Additionally, DT led to a 15% reduction in energy consumption. Enhanced operational efficiency led to lower fuel and energy usage across the fleet, contributing to the company's sustainability goals. Finally, from a marketing and consumer perspective, DT greatly improved the passenger experience. Real-time simulations helped to manage passenger flow more effectively, reducing overcrowding and improving overall customer satisfaction.

By implementing DT, Glob-South-Net transformed its approach to public transportation management. The ability to monitor vehicle health, optimize schedules, and proactively maintain infrastructure reduced costs, improved service reliability, and enhanced the overall passenger experience. As a result, Glob-South-Net became a global leader in the use of digital technologies to modernize public transportation.

Eurasia-E-Net: Digital Twins in the Electronics Industry

This company is a global electronics manufacturer specializing in the production of consumer electronics such as smartphones, laptops, and wearables. With a vast network of factories and suppliers, Eurasia-E-Net faces significant challenges in managing its supply chain, ensuring product quality, and maintaining high levels of operational efficiency. The company adopted Digital Twins to improve manufacturing processes, enhance product innovation, and optimize its global supply chain.

Prior to using DT technology, Eurasia-E-Net faced challenges in managing the manufacturing complexity, ensuring consistent product quality, making the supply chain fully visible to managers, and shortening the product development cycle. Producing high-tech electronics requires precise coordination between multiple factories and suppliers, each with its own set of standards and capabilities. Ensuring consistent product quality across different manufacturing facilities was a constant challenge, leading to occasional defects and recalls. Eurasia-E-Net's supply chain was vast and complex, making it difficult to maintain real-time visibility into inventory levels, supplier performance, and production schedules. As a leader in innovation, Eurasia-E-Net needed to shorten its product development cycle while ensuring the highest levels of quality and performance.

Eurasia-E-Net implemented a comprehensive Digital Twin solution that integrated its manufacturing operations, supply chain management, and product development processes. Each of the company's production facilities was digitized, with real-time data flowing from sensors embedded in the manufacturing equipment. These Digital Twins provided a virtual model of the factory floor, allowing the company to monitor production rates, equipment health, and product quality. Any deviations from standard operating procedures were immediately flagged, allowing for corrective actions to be taken before defects occurred. The company also created Digital Twins for its entire supply chain, from raw material suppliers to finished goods warehouses. This provided real-time visibility into inventory levels, supplier performance, and shipping schedules, allowing Eurasia-E-Net to optimize its supply chain operations and avoid disruptions. DT technology was also deployed in the product development process. Digital Twins were used to create virtual prototypes of new products. These virtual models were subjected to rigorous testing and simulations, allowing the company to identify potential issues and optimize designs before physical prototypes were built. This significantly reduced the time and cost associated with product development. Finally, in terms of quality control, by analyzing data from the Digital Twins of its manufacturing equipment, Eurasia-E-Net was able to predict when machines would require

DOI: 10.23860/MGDR-2024-09-01-04

maintenance, minimizing downtime and ensuring consistent product quality. This also allowed the company to maintain high production yields while minimizing waste.

Overall use of DT technology led to a 30% reduction in product development time. The use of virtual prototypes and simulations significantly shortened the product development cycle, allowing Eurasia-E-Net to bring new products to market faster. There was also a 20% improvement in supply chain efficiency. Real-time visibility into the supply chain allowed Eurasia-E-Net company to reduce inventory holding costs, improve supplier performance, and avoid production delays. Digital Twins provided real-time insights into manufacturing processes, allowing Eurasia E-Net to detect and address quality issues before they escalated, leading to fewer product recalls and customer complaints. Predictive maintenance and optimized production processes reduced machine downtime and minimized waste, resulting in lower overall operational costs.

Eurasia-E-Net's use of Digital Twin technology has revolutionized its approach to manufacturing and supply chain management. By creating real-time digital replicas of its factories, products, and supply chain, the company has been able to improve operational efficiency, enhance product quality, and accelerate innovation. Digital Twins have positioned Eurasia-E-Net as a leader in the electronics industry, driving both growth and sustainability.

Problems with Implementing DT Technologies

Implementing Digital Twin technologies can bring significant benefits, but it also comes with several challenges. In follow-up interviews with management, all three companies reported multiple issues with the DT technologies. Across the three companies, five major issues surfaced when adopting Digital Twins. These are summarized in Table 1. The contents of this table are based on our case study observations and interviews as well as our own (evolving) understanding of DT technologies: what they are capable of, where they need improvement, and what the future may hold.

Table 1: Five Major DT Challenges

DT Implementation Challenge	***Explanation/Elaboration***	***Solutions – Suggestions for Future Enhancements in DT Technologies***
Data Management and Integration	Digital Twins require massive amounts of data from various sources, such as IoT devices, sensors, and business systems. Integrating this data, especially when it comes from disparate and often incompatible systems, can be complex. Ensuring data accuracy, consistency, and timeliness is critical to the effectiveness of the Digital Twin.	Companies need robust data management strategies and advanced integration platforms that can gather, process, and synchronize data from multiple sources in real-time.
High Initial Costs and Investment	Digital Twin technologies can require substantial upfront investment in hardware (sensors, IoT devices), software (data analytics platforms, machine learning models), and skilled personnel. For smaller companies or industries with tight margins, the cost of setting up and maintaining a Digital Twin can be prohibitive.	Organizations must carefully assess the ROI of Digital Twin projects, starting with smaller pilot projects that demonstrate clear value before scaling up. Additionally, cloud-based or third-party Digital Twin solutions may reduce upfront costs.
Cybersecurity Risks	As Digital Twins are connected to physical assets and systems, any breach in the digital space can directly affect physical operations, creating serious security vulnerabilities. Continuous data flow and integration with operational technologies can increase the attack points for cyber threats.	Companies need to implement strong cybersecurity protocols, including encryption, secure communication channels, and real-time monitoring to detect and mitigate threats. Regular updates and security audits are also essential to minimize vulnerabilities.

DT Implementation Challenge	***Explanation/Elaboration***	***Solutions – Suggestions for Future Enhancements in DT Technologies***
Lack of Skilled Talent	Implementing and managing Digital Twins requires a specialized skill set, combining knowledge of IoT, AI, data analytics, and industry-specific operational expertise. The shortage of qualified personnel with experience in these areas is a significant barrier.	Companies must invest in training and development for existing staff or hire experts in fields like data science, AI, and cybersecurity. Collaborating with universities, startups, or technology partners can also help bridge the talent gap.
Complexity in Model Accuracy and Simulation	Creating accurate and reliable Digital Twin models that effectively represent real-world systems is a major technical challenge. If the virtual model does not accurately reflect the physical system, simulations and predictions can be misleading, reducing the value of the Digital Twin.	Continuous validation and calibration of the Digital Twin model against real-world data is essential. Advanced simulation tools, machine learning algorithms, and domain expertise are needed to create and maintain high-fidelity models that evolve with the physical system.

Concluding Observations

Successfully implementing Digital Twin technologies requires overcoming these challenges through careful planning, investment in infrastructure and talent, robust cybersecurity measures, and maintaining high-quality data and model accuracy. Addressing these issues is crucial for organizations to fully realize the benefits of Digital Twins.

Digital Twins are rapidly becoming an indispensable tool across a wide range of industries. Lorry-Planet in the trucking sector, Glob-South-Net in the public transportation domain, and Eurasia-E-Net in the global electronics industry have all leveraged this cutting-edge technology to improve operational efficiency, reduce costs, and enhance customer satisfaction. By creating real-time digital replicas of physical assets and processes, these companies have unlocked new levels of insight and control, driving innovation and competitive advantage in their respective fields. As Digital Twin technology continues to evolve, its impact on industries around the world is set to grow even further.

DOI: 10.23860/MGDR-2024-09-01-04

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