Chapter 1
AI, Digital Twins, and Sustainability in Supply Chains: Foundations, Innovations, and Future Directions

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ABSTRACT

This chapter explores how Artificial Intelligence (AI) and digital twins are reshaping sustainable supply chains by integrating intelligence, transparency, and resilience into global logistics systems. AI enables predictive analytics, green routing, and automation to optimize resources while minimizing waste and emissions. Digital twins create real-time, virtual replicas of supply networks, allowing proactive monitoring, scenario testing, and energy optimization. Together, these technologies advance ESG compliance, net-zero strategies, and circular economy practices. Case studies from Unilever and Siemens-DHL highlight practical adoption, while discussions on blockchain, quantum AI, and autonomous operations illustrate future trends. The chapter concludes by identifying challenges such as governance, interoperability, and costs, and proposes pathways toward self-adaptive, eco-resilient supply chains.

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1. INTRODUCTION

Global supply chains are experiencing an epoch of two major transformations. Technological development alongside market volatility and the need to be greener has put tremendous pressure on the more traditional, focused on cost efficient, supply chains. In light of issues such as the COVID-19 Pandemic, climate shifts, and geopolitical shifts, the need for more adaptive and intelligent supply chain digital systems has grown. In this regard, Artificial Intelligence (AI) and digital twins offer some of the more advanced supply chain capabilities. While AI assists with analytics in the domains of predictive decision-making, real-time optimization and intelligent automation, digital twins offer real-time virtual models of physical systems, assets, flows and processes networks (Li & Liu, 2023). By the two working at the same time, there is great potential to operationalize and use to advance greenhouse gas emissions frameworks, the circular economy, and fulfill other bottom line operational demands. This chapter reflects on these as the new foundation of next generation sustainable supply chains.

1.1 Context of Supply Chain Transformation

Increase in complexity of modern supply chains includes fluctuations in consumer demand, and shifting regulatory requirements. Unlike the past where innovations rewarding agility and resiliency were omitted, Advanced case studies, especially in global logistics, serve to highlight the consequences of tropical cyclones, oil shocks, global pandemics, and other phenomena on shipping and supply chains. Additionally, the inability to abandon the goal of sustainability has now been embraced religiously. This mainly to foster a culture of boundless ‘cancel culture’ on emissions, waste, and, embrace circular business strategies. To such an extent, the compulsory and integrative frameworks of digitalization, sophistication in data technologies, and their unquestioned constituents. Supply chains now become resilient, intelligent, and to an extent, ecosystems. The connections to such are hyper integration through Advanced analytics, the IoT, and Unified cloud platforms. Business intelligence now, operates on flexible infrastructure, immediate, and actionable real-time scopes to pursue operations that are sustainable, and resilient. These establish the primary criteria of investments for the propagation of strategically responsive frameworks to AI, digital twin technologies, and the other foundational frameworks of intelligent operations (De Angelis et al., 2018).