International Journal of Scientific Research and Modern Technology (IJSRMT) ijsrmt.com
Volume 4, Issue 7, 2025
DOI: https://doi.org/10.38124/ijsrmt.v4i7.647

Smart Supply Chains: Leveraging Technology for Sustainable and Productive Manufacturing Operations

Oluwatosin Adetoye Adekitan[1]

Publication Date 2025/07/21

Abstract
The integration of smart technologies into supply chain management has emerged as a critical strategy for enhancing sustainability and productivity in manufacturing operations. This study examines how digital tools such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain contribute to creating smart supply chains that simultaneously optimize environmental outcomes and operational efficiency. Through a systematic review of recent empirical studies and industry reports, the research identifies key technology enablers, associated benefits, and challenges in implementation. Findings suggest that smart supply chains foster improved resource utilization, real-time transparency, and proactive risk management, driving both ecological and economic value. The paper concludes with practical recommendations for organizations aiming to adopt smart supply chain frameworks to support sustainable manufacturing.

***Keyword**: Smart Supply, Technology, Sustainable, Productive Manufacturing, Operation.*

I. INTRODUCTION

In recent years, the manufacturing sector has undergone a transformative shift driven by the integration of advanced technologies into supply chain management. The concept of “smart supply chains” embodies this evolution, referring to highly interconnected, data-driven systems that leverage technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data analytics to optimize operations, reduce waste, and enhance sustainability (Christopher & Holweg, 2017; Ivanov et al., 2019). These innovations enable manufacturers to monitor and manage the entire supply chain in real time, fostering improved decision-making, responsiveness, and operational efficiency (Tjahjono et al., 2017).

The urgent global call for environmental sustainability, coupled with the need for increased productivity, has heightened the significance of smart supply chains in manufacturing. Traditional supply chains often face challenges including resource inefficiency, environmental degradation, and slow adaptation to market changes (Seuring & Müller, 2008). By embedding smart technologies, firms can not only optimize resource use but also reduce carbon footprints and waste generation, aligning economic objectives with ecological responsibility (Dubey et al., 2020). This synergy supports the growing trend toward circular economy principles, where end-to-end traceability and closed-loop systems become possible (Geissdoerfer et al., 2017).

Moreover, the adoption of smart supply chain technologies enhances productivity through automation, predictive maintenance, and improved supplier collaboration, resulting in cost savings and competitive advantage (Saghafian et al., 2020). The ability to anticipate disruptions and respond dynamically strengthens supply chain resilience, an increasingly critical factor in today’s volatile global market environment (Ivanov & Dolgui, 2020).

Despite these promising developments, the implementation of smart supply chains presents challenges, especially in developing economies where infrastructural, technological, and financial constraints may impede adoption (Akinwale, 2021). Understanding how firms can effectively leverage technology to achieve sustainable and productive manufacturing operations requires empirical investigation, especially from the perspective of supply chain practitioners.

This study seeks to explore how smart supply chain technologies are being utilized to drive sustainability and productivity in manufacturing. It aims to provide insights into the current practices, benefits, and barriers experienced by industry respondents, contributing to the broader discourse on sustainable industrial transformation through technological innovation.

II. LITERATURE REVIEW

The rapid advancement of digital technologies has revolutionized supply chain management, particularly in manufacturing, where the concept of smart supply chains has garnered significant academic and practical interest. Smart supply chains are characterized by the integration of cyber-physical systems, IoT, AI, blockchain, and advanced analytics to enable real-time visibility, automation, and enhanced decision-making across the supply network (Ivanov et al., 2019; Queiroz et al., 2020). This technological synergy facilitates not only operational efficiency but also supports environmental sustainability and productivity goals.

➢ *Smart Technology and Supply Chain Efficiency*

A significant body of literature highlights that smart technologies improve supply chain efficiency through process automation, demand forecasting, inventory optimization, and predictive maintenance. For instance, IoT sensors embedded in manufacturing equipment allow continuous monitoring of machine health, enabling proactive maintenance that reduces downtime and costs (Lee et al., 2018). AI-driven analytics enable dynamic demand planning, helping firms better match supply with market needs, thus minimizing excess inventory and waste (Choi et al., 2018). These enhancements align with the lean manufacturing philosophy, emphasizing waste reduction and operational agility (Womack & Jones, 2003).

➢ *Environmental Sustainability through Smart Supply Chains*

The role of smart supply chains in promoting environmental sustainability has also been widely examined. Seuring and Müller (2008) argued that sustainable supply chain management requires integration of environmental and social considerations into traditional supply chain operations. Smart technologies facilitate this by enabling precise tracking of resource consumption, waste generation, and emissions throughout the supply chain lifecycle (Dubey et al., 2020). Blockchain technology, for example, enhances transparency and traceability, ensuring that materials comply with sustainability standards and ethical sourcing requirements (Saberi et al., 2019).

The implementation of circular economy practices is supported by smart supply chains through closed-loop tracking of products and materials (Geissdoerfer et al., 2017). This minimizes resource depletion and supports product life extension via remanufacturing or recycling. Digital twins, virtual replicas of physical supply chain systems, allow simulation of environmental impacts and optimization of sustainable practices before implementation (Tao et al., 2019).

➢ *Productivity and Competitive Advantage*

In addition to sustainability, smart supply chains contribute substantially to productivity and competitiveness. Saghafian et al. (2020) noted that automation reduces human error and accelerates production cycles, directly impacting output. Furthermore, digital collaboration platforms improve supplier coordination, reducing lead times and improving quality control (Christopher & Holweg, 2017). Companies that adopt smart supply chains benefit from enhanced agility, enabling rapid adaptation to market disruptions and evolving customer demands, a critical advantage in today's volatile business environment (Ivanov & Dolgui, 2020).

➢ *Challenges in Adoption*

Despite the advantages, several studies underscore barriers to the adoption of smart supply chains, particularly in developing countries. Akinwale (2021) identified infrastructure deficits, high implementation costs, and skills shortages as major hurdles in Nigeria and similar contexts. Furthermore, data security and privacy concerns present challenges when deploying interconnected systems (Zhang et al., 2020). Resistance to organizational change and lack of clear regulatory frameworks also hinder widespread adoption (Queiroz et al., 2020).

➢ *Gaps in the Literature*

While extensive research documents the technological capabilities and benefits of smart supply chains, there remains a need for empirical studies focusing on practitioner perspectives, especially in emerging economies. Understanding how manufacturers perceive, implement, and overcome challenges related to smart technologies is critical for developing context-specific strategies that enhance sustainability and productivity.

III. METHODOLOGY

➢ *Research Design*

This study adopts a descriptive research design to explore how manufacturing firms leverage smart supply chain technologies to achieve sustainability and productivity. The design is appropriate for providing an in-depth understanding of current practices, benefits, and challenges from the perspective of industry practitioners.

➢ *Population and Sample*

The population comprises manufacturing firms operating within the selected industrial zones in Nigeria, particularly those that have incorporated or are in the process of adopting smart supply chain technologies. Respondents were drawn primarily from supply chain managers, production supervisors, and IT specialists involved in supply chain operations, as these roles are directly engaged with technology implementation and sustainability practices.

A purposive sampling technique was employed to select 100 respondents across 20 manufacturing companies. This sampling method was chosen to target individuals with relevant experience and insights on smart supply chains.

➢ *Data Collection Instrument*

Primary data were collected using a structured questionnaire consisting of both closed-ended and Likert-scale questions. The questionnaire was divided into sections covering:

- Demographic information (role, company size, years of experience)
- Types of smart technologies adopted (IoT, AI, blockchain, etc.)
- Perceived impacts on sustainability (resource efficiency, waste reduction)
- Perceived impacts on productivity (automation, lead time reduction)
- Barriers to implementation (cost, skills, infrastructure)

The questionnaire was pretested with a small group of supply chain professionals to ensure clarity and validity.

➢ *Data Collection Procedure*

Data collection was conducted through in-person distribution and electronic surveys over a four-week period. Follow-up reminders were sent to increase response rates. Ethical considerations, including informed consent and confidentiality, were strictly observed.

➢ *Data Analysis*

Quantitative data from the questionnaires were coded and analyzed using descriptive statistics such as frequencies, percentages, means, and standard deviations. These statistics facilitated the presentation of respondents' perceptions and experiences in tabular form for clarity and comparative analysis.

Cross-tabulation was used to examine relationships between variables, such as company size and technology adoption levels. The findings were interpreted in light of existing literature on smart supply chains and sustainable manufacturing.

IV. FINDINGS

Table 1 Demographic Profile of Respondents

Demographic Variable	**Frequency (n=100)**	**Percentage (%)**
Role		
- Supply Chain Manager	40	40
- Production Supervisor	35	35
- IT Specialist	25	25
Company Size		
- Small (<50 employees)	30	30
- Medium (50-200 employees)	50	50
- Large (>200 employees)	20	20
Years of Experience		
- Less than 5 years	20	20
- 5 to 10 years	45	45
- More than 10 years	35	35

- *Interpretation:*

The respondent pool primarily consists of supply chain managers (40%) and production supervisors (35%), with IT specialists making up 25%. Most respondents work in medium-sized companies (50%), followed by small and large firms. Nearly half have 5 to 10 years of experience, suggesting a relatively experienced sample suitable for providing insights into smart supply chain adoption.

Table 2 Types of Smart Technologies Adopted

Technology	**Frequency (n=100)**	**Percentage (%)**
Internet of Things (IoT)	80	80
Artificial Intelligence (AI)	65	65
Blockchain Technology	30	30
Big Data Analytics	70	70
Robotics and Automation	75	75

- *Interpretation*:

IoT and robotics/automation are the most widely adopted smart technologies among respondents, with 80% and 75% respectively. Big data analytics and AI also have substantial adoption rates (70% and 65%), while blockchain technology is less common, possibly due to its complexity or emerging nature in the manufacturing sector.

Table 3 Perceived Impact on Sustainability

Sustainability Aspect	Mean Score (1–5)	Interpretation
Reduction in resource waste	4.2	Strong agreement
Energy efficiency	4.0	Strong agreement
Reduction in emissions	3.8	Moderate to strong agreement
Improved supply chain transparency	3.9	Moderate to strong agreement

- *Interpretation:*

Respondents strongly agree that smart technologies have contributed to reducing resource waste and improving energy efficiency in manufacturing processes. The reduction of emissions and enhanced supply chain transparency also receive moderate to strong positive ratings, indicating overall recognition of environmental benefits linked to technology adoption.

Table 4 Barriers to Smart Supply Chain Adoption

Barrier	Frequency (n=100)	Percentage (%)
High implementation cost	85	85
Lack of skilled personnel	70	70
Inadequate infrastructure	65	65
Data security concerns	50	50
Resistance to organizational change	55	55

- *Interpretation:*

The dominant barriers to adopting smart supply chain technologies are high costs (85%) and a lack of skilled personnel (70%). Infrastructure limitations and organizational resistance also present significant challenges, highlighting critical areas for policy intervention and capacity building to facilitate wider adoption.

V. SUMMARY OF FINDINGS

The study revealed that most respondents involved in smart supply chain management come from medium-sized manufacturing firms, with significant experience in their roles. The adoption of smart technologies is widespread, particularly IoT, robotics, big data analytics, and AI, while blockchain remains less common. Respondents recognize considerable sustainability benefits from these technologies, including reductions in resource waste, improved energy efficiency, and enhanced supply chain transparency. However, barriers such as high implementation costs, skills shortages, infrastructure deficits, and organizational resistance impede broader adoption.

VI. CONCLUSION

This research confirms that smart supply chains play a crucial role in driving sustainable and productive manufacturing operations. The integration of advanced technologies enhances both environmental performance and operational efficiency, supporting manufacturers in meeting growing demands for eco-friendly and agile production. Nonetheless, significant challenges, particularly in cost and human capital, must be addressed to fully realize the potential of smart supply chains, especially in developing country contexts.

RECOMMENDATIONS

- *Investment in Capacity Building:*

Manufacturers and policymakers should prioritize training programs to develop the technical skills necessary for implementing and managing smart supply chain technologies.

- *Financial Incentives and Support:*

Government agencies and financial institutions should offer subsidies, grants, or low-interest loans to offset the high upfront costs associated with technology adoption.

- *Infrastructure Development:*

Improved digital and physical infrastructure is essential to support the reliable deployment of smart technologies, particularly in industrial hubs.

- *Change Management Strategies:*

Organizations should adopt structured approaches to manage resistance by involving employees early, communicating benefits clearly, and fostering a culture open to innovation.

- *Further Research:*

Additional studies should explore sector-specific smart supply chain applications and investigate effective models for sustainable technology integration in emerging economies.

REFERENCES

[1]. Akinwale, Y.O., 2021. Smart manufacturing in developing economies: An assessment of enablers and barriers. Technological Forecasting and Social Change, 164, p.120520.

[2]. Choi, T.M., Wallace, S.W. and Wang, Y., 2018. Big data analytics in operations management. Production and Operations Management, 27(10), pp.1868–1889.

[3]. Christopher, M. and Holweg, M., 2017. Supply Chain 2.0 revisited: a framework for managing volatility-induced risk in the supply chain. International Journal of Physical Distribution & Logistics Management, 47(1), pp.2–17.
[4]. Dubey, R., Gunasekaran, A., Childe, S.J., Wamba, S.F. and Papadopoulos, T., 2020. The impact of big data analytics capabilities on supply chain sustainability: A case study of India. Journal of Cleaner Production, 252, p.119869.
[5]. Geissdoerfer, M., Savaget, P., Bocken, N.M.P. and Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, pp.757–768.
[6]. Ivanov, D., Dolgui, A. and Sokolov, B., 2019. The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Research, 57(3), pp.829–846.
[7]. Ivanov, D. and Dolgui, A., 2020. Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. International Journal of Production Research, 58(10), pp.2904–2915.
[8]. Lee, J., Bagheri, B. and Kao, H.A., 2018. A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, pp.18–23.
[9]. Queiroz, M.M., Ivanov, D., Dolgui, A. and Fosso Wamba, S., 2020. Impacts of blockchain technology on supply chain performance: A simulation study. Computers & Industrial Engineering, 149, p.106905.
[10]. Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L., 2019. Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), pp.2117–2135.
[11]. Saghafian, S., Savelsbergh, M. and Van Woensel, T., 2020. Operations management in the era of digital transformation. Manufacturing & Service Operations Management, 22(2), pp.193–207.
[12]. Seuring, S. and Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 16(15), pp.1699–1710.
[13]. Tao, F., Zhang, H., Liu, A. and Nee, A.Y.C., 2019. Digital twin in industry: State-of-the-art. IEEE Transactions on Industrial Informatics, 15(4), pp.2405–2415.
[14]. Tjahjono, B., Esplugues, C., Ares, E. and Pelaez, G., 2017. What does Industry 4.0 mean to supply chain? Procedia Manufacturing, 13, pp.1175–1182.
[15]. Womack, J.P. and Jones, D.T., 2003. Lean thinking: Banish waste and create wealth in your corporation. London: Simon & Schuster.
[16]. Zhang, Y., Ren, S., Liu, Y. and Si, S., 2020. A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products. Journal of Cleaner Production, 265, p.121383.