

# Hype or Reality? Exploring how Food-Processing Firms Interpret and Implement Industry 4.0 Technologies in Supply Chain Operations

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## Abstract

The projection of Industry 4.0 technologies in the Nigerian manufacturing sector has led to widespread optimism about achieving smarter, more efficient, and agile supply chains. However, in practice, many firms, including those within the food-processing industry, struggle to move beyond conceptual enthusiasm toward meaningful implementation. This study explored how food-processing firms interpret and operationalise Industry 4.0 technologies within their supply chain operations, addressing the persistent gap between the perceived “hype” and the lived “reality” of digital transformation. Guided by Sensemaking Theory and the Technology–Organization–Environment (TOE) framework, the study adopted an interpretivist philosophy and an exploratory qualitative design. Semi-structured interviews were conducted with ten supply chain managers in Calabar, Cross River State, selected through purposive and snowball sampling. The data were analysed using Braun and Clarke’s reflexive thematic analysis. Findings indicate that while managers associate Industry 4.0 with innovation, traceability, and operational efficiency, their interpretations vary widely and are influenced by organizational culture, leadership orientation, and contextual pressures. Implementation remains incremental and often reactive, constrained by infrastructural limitations, skill shortages, and low digital maturity. The study concludes that realising the promises of Industry 4.0 in the Nigerian food-processing supply chain requires aligning technological ambitions with organizational capabilities and contextual realities. Practically, it underscores the importance of strategic alignment, workforce development, and ecosystem collaboration. The study contributes by providing context-specific insights into how sensemaking and organizational readiness shape the translation of Industry 4.0 from conceptual promise to operational reality in food-processing firms.

**Keywords:** Food-processing Industry, Industry 4.0, Supply Chain Operations, Internet of things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA).

## Introduction

Industry 4.0 technologies are a collection of advanced digital tools and systems that enable real-time data collection, automation, and enhanced connectivity across supply chain operations (Farrukh et al., 2025). These technologies include the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics (BDA), Cyber-Physical Systems (CPS), Digital Twins, and blockchain (Sharma et al., 2022). Prior to their introduction into the food-

processing industry, companies relied predominantly on traditional, often manual, processes for production planning, inventory management, and logistics, which were typically fragmented, time-consuming, and prone to errors, thereby limiting visibility, responsiveness, and overall supply chain efficiency (Ali et al., 2021). In emerging economies such as Nigeria, these limitations are often further compounded by infrastructural deficits, energy instability, fragmented supplier networks, and limited digital capabilities, which intensify supply chain vulnerabilities and reduce operational resilience.

Against this backdrop, Industry 4.0 technologies are considered necessary for food-processing firms, especially to enhance supply chain integration, increase operational efficiency, ensure product quality and safety, and enable rapid adaptation to changing market demands and environmental conditions (Zhao et al., 2025). In this effort, several of these technologies are gradually being applied, particularly IoT for real-time monitoring of production and inventory, AI and Big Data Analytics for demand forecasting and process optimisation, automation and robotics for streamlined manufacturing, and blockchain for traceability and transparency across the supply chain (da Silva & Sehnem, 2025; Ellahi et al., 2025). In Nigeria, where food safety concerns, informal distribution channels, and regulatory enforcement gaps remain persistent challenges, such pressures further amplify the perceived relevance of digital transformation. Consequently, digital transformation is rapidly reshaping the food-processing industry, with many firms considering it critical for future growth (Khan & Emon, 2025). In fact, Riaz et al. (2025) maintained that the rapid emergence of Industry 4.0 has generated considerable attention for its potential to transform supply chain operations for food-processing firms.

While previous research demonstrates measurable benefits of these technologies, such as improved operational efficiency, supply chain integration, visibility, innovation, resilience, and sustainability (Fatorachian & Kazemi, 2021; Sharma et al., 2022; Khan & Emon, 2025; Zhu et al., 2022; Ghadge et al., 2020; Marinagi et al., 2023; Tortorella et al., 2024; Piprani et al., 2024; Farrukh et al., 2025; Brookbanks & Parry, 2024; Pandey et al., 2025; Jain et al., 2024), there remains a notable gap in understanding how these technologies are interpreted, adopted, and experienced in practice, particularly within the food-processing sector in developing economies. Quantitative studies often emphasise performance outcomes and mediating mechanisms but provide limited insight into how managers perceive the meaning and relevance of Industry 4.0, how technologies are actually integrated into supply chain processes, and the contextual and organisational factors influencing implementation outcomes. This limitation is especially pronounced in the Nigerian context, where infrastructural volatility, fluctuating exchange rates, skills shortages, and institutional pressures may significantly shape managerial interpretation and technology deployment. Moreover, while benefits are frequently anticipated in theory, the realities of operational constraints, cultural dynamics, and environmental influences in food-processing firms may lead to discrepancies between expected and realised outcomes. This study, therefore, sought to address these gaps by exploring, through a qualitative lens,

how food-processing firms in Nigeria interpret Industry 4.0, how technologies are adopted and integrated, how managers experience their impact on operational efficiency, and which organisational, cultural, and contextual factors shape the gap between anticipated and actual benefits. By moving from the “hype” of Industry 4.0 to its lived reality, this research aimed to provide an empirically grounded understanding that captures managerial perspectives, sector-specific challenges, and the nuanced processes that underlie successful digital transformation in food-processing supply chains within an emerging economy setting.

## Literature Review

### *Theoretical Framework*

This study draws on two complementary theoretical lenses: Weick’s (1995) sensemaking theory and the technology–organization–environment (TOE) framework (Tornatzky & Fleischer, 1990). Sensemaking theory explains how individuals interpret, give meaning to, and act upon complex and uncertain situations. Its core constructs include enactment (how managers create their environment through actions), retrospection (making sense of events after they occur), plausibility (the subjective sense of what makes sense), and identity construction (how decisions are shaped by who managers perceive themselves to be). In the context of this study, sensemaking theory helps explain how managers in food-processing firms interpret and respond to Industry 4.0 technologies, including how their understanding is influenced by prior experiences, knowledge, and interactions with employees. For example, managerial interpretations determine which tools are prioritised, how risks are perceived, and how implementation strategies are framed.

The TOE framework provides a complementary organisational perspective. It emphasises that technology adoption is influenced by three structural dimensions: technology (availability, compatibility, and complexity of tools), organisation (resources, skills, processes, and internal readiness), and environment (market pressures, regulatory requirements, and external partnerships). In this study, the TOE framework guides the examination of organisational and environmental conditions that enable or constrain Industry 4.0 adoption, such as infrastructure, workforce capability, and industry standards. By integrating sensemaking theory and the TOE framework, this study recognises that adoption outcomes emerge from both managerial interpretation and structural conditions. Managerial sensemaking shapes decisions about which technologies to adopt and how to implement them, while organisational and environmental factors determine the feasibility and success of these decisions. This integrated lens informs the study’s analytical approach by guiding interview questions on managerial perceptions, organisational capabilities, and environmental pressures, and by structuring thematic analysis around both individual and organisational determinants. Figure 1 (optional) summarises the combined framework, showing how managerial sensemaking interacts with TOE dimensions to influence Industry 4.0 adoption in food-processing firms.

***The Changing Nature of Supply Chain Operations***

Supply chain operations have changed significantly in the digital era, driven by technological advances, globalisation, and rising consumer demands for speed, quality, and transparency. Farrukh et al. (2025) highlight the broad structural changes and overall efficiency improvements enabled by digitalisation, showing how supply chains are becoming more integrated and less fragmented. In comparison, Sharma et al. (2022) and Khan and Emon (2025) focus on the operational mechanisms, emphasising how automation, real-time monitoring, and data-driven decision-making reduce errors, improve coordination across production, inventory, and distribution, and allow managers to respond more quickly to changing conditions. While Sharma et al. (2022) place efficiency at the centre of Industry 4.0's benefits, Marinagi et al. (2023) argue that these technologies do more than optimise operations; they also enhance resilience and responsiveness by enabling predictive analytics, proactive risk management, and better handling of disruptions. Brookbanks and Parry (2024) extend this perspective by demonstrating that digital integration fosters collaboration across internal departments, suppliers, and customers, breaking down information silos and enabling adaptive responses to unexpected events.

This focus on relational and network-level benefits complements the operational and resilience-oriented views of other authors. Pandey et al. (2025) and Jain et al. (2024) emphasise the strategic role of digital supply chains, showing that they now serve as enablers of innovation, sustainability, and competitive advantage. Their perspectives differ in emphasis: Pandey et al. (2025) foreground flexibility and resilience in unpredictable environments, while Jain et al. (2024) highlight supply chain visibility and regulatory compliance as central to performance. Essentially, these studies illustrate that the adoption of Industry 4.0 is multi-dimensional. It is not only about improving efficiency but also about building adaptive, resilient, and collaborative networks while strengthening the strategic contribution of supply chains. The literature agrees on the importance of digital transformation for both operational and strategic performance but debates remain on which aspects (efficiency, resilience, collaboration, or compliance) are most critical. A balanced position recognises that all these dimensions interact: efficiency gains support resilience, collaboration enhances responsiveness, and visibility ensures compliance and trust.

***Industry 4.0 Technologies in Supply Chain Operations***

Industry 4.0 technologies are transforming supply chain operations by enabling greater automation, connectivity, and data-driven decision-making (Fatorachian & Kazemi, 2021). While Fatorachian and Kazemi (2021) emphasise that these technologies improve supply chain performance through integration, transparency, and efficiency, Ali et al. (2021) argue that they also play a crucial role in mitigating disruptions, particularly in sectors like food processing where volatility and perishability are high. Sharma et al. (2022) highlight that

Industry 4.0 acts as a mediator between traditional supply chain practices and performance outcomes, suggesting that adoption alone is insufficient without effective integration into organisational processes. In contrast, Khan and Emon (2025) focus on the operational mechanisms, showing that technologies like IoT, AI, and Big Data Analytics enhance real-time monitoring, reduce errors, and improve coordination across production, inventory, and logistics networks. Marinagi et al. (2023) extend this perspective by suggesting that these technologies not only optimise operations but also strengthen resilience and responsiveness, allowing firms to anticipate and respond to disruptions proactively. Brookbanks and Parry (2024) further support this view, showing that digital integration facilitates collaboration across internal and external stakeholders, reducing silos and enhancing adaptability. Similarly, Jain et al. (2024) demonstrate that supply chain visibility, supported by Industry 4.0, is critical for building resilience, particularly under dynamic environmental conditions. However, Zhu et al. (2022) caution that technology adoption alone does not automatically improve performance; alignment with processes and integration across the supply chain are essential.

Other authors focus on strategic and sustainability dimensions. Piprani et al. (2024) and Farrukh et al. (2025) argue that Industry 4.0 adoption, combined with lean, agile, and green practices, enhances sustainable performance and competitiveness, while Pandey et al. (2025) emphasise flexibility and adaptive capabilities in volatile markets. Zhao et al. (2025) highlight the importance of sustainability-driven adoption, showing that technologies can balance efficiency with environmental responsibility. Riaz et al. (2025) link visibility, traceability, and resilience sequentially to improved performance, demonstrating that benefits are multi-layered and interconnected. Basically, these studies suggest that Industry 4.0 technologies are multi-dimensional in the sense that they drive operational efficiency, enhance resilience, foster collaboration, and support strategic goals including sustainability and competitiveness. The literature agrees on their importance but debates remain regarding which benefits are most critical. Essentially, scholars agree that effective adoption requires integration, alignment, and contextual adaptation, showing that the full potential of Industry 4.0 in supply chains is realised only when technologies are embedded into both operational and strategic processes (da Silva & Sehnem, 2025; Ellahi et al., 2025; Zhao et al., 2025).

#### ***Industry 4.0 Impact on Supply Chain Performance: Prior Studies and Research Gap***

In a study by Fatorachian and Kazemi (2021), it was found that Industry 4.0 technologies enhance supply chain performance by improving integration, transparency, and information sharing across supply chain processes. Their review showed that digital technologies strengthen procurement, production, inventory management, and retail operations by enabling greater automation and process digitisation. The authors concluded that the adoption of Industry 4.0 leads to significant performance improvements because it supports more coordinated, data-driven, and efficient supply chain operations. Sharma et al. (2022) found that supply chain management practices significantly influence the

adoption of Industry 4.0 technologies, and that these technologies in turn have a strong positive effect on supply chain performance. The study also showed that Industry 4.0 acts as a mediator between supply chain practices and performance outcomes. In a study by Khan and Emon (2025), it was found that Industry 4.0 adoption significantly improves digital supply chain integration, supply chain innovation, and supply chain visibility, all of which collectively enhance overall supply chain performance. The study showed that Industry 4.0 strengthens integration through real-time communication and reduces process fragmentation, drives innovation by supporting adaptability and continuous improvement, and increases visibility by enhancing traceability and transparency.

Zhu et al. (2022) also revealed that ICT alignment does not directly improve supply chain performance, but it significantly enhances performance when mediated by supply chain integration. The study also showed that operational performance further mediates the relationship between supply chain integration and financial performance. The authors concluded that ICT alignment contributes to stronger supply chain outcomes only when it is effectively integrated into supply chain processes. Ghadge et al. (2020) revealed that Industry 4.0 introduces both significant challenges and opportunities for supply chains, with various strategic, organisational, technological, and ethical factors acting as drivers and barriers to its implementation. The simulation results showed that these drivers and barriers collectively influence how effectively Industry 4.0 technologies can be integrated into supply chain operations. Moreover, Marinagi et al. (2023) highlighted that Industry 4.0 technologies, while not directly impacting overall supply chain resilience, significantly strengthen its constituent elements such as flexibility, agility, visibility, collaboration, and information sharing. Their literature review identified that innovations including IoT, AI, Digital Twins, and Blockchain enhance key performance indicators (KPIs) that underpin a Resilient Supply Chain 4.0. The authors concluded that integrating these technologies into supply chain processes can effectively support the development of resilient, adaptive, and responsive supply chains.

Tortorella et al. (2024) found that Industry 4.0 technologies improve healthcare supply chain performance, but their effect is stronger when resilience abilities, particularly adaptive and restorative, are developed. Sensing and communication technologies also directly enhance performance. The study concluded that combining digital tools with resilience capabilities is key for effective supply chain outcomes. In a similar study, Piprani et al. (2024) found that Industry 4.0 technologies significantly influence lean, agile, resilient, and green supply chain practices. Agile and resilient practices were shown to partially mediate the relationship between these technologies and overall supply chain performance. The authors concluded that integrating Industry 4.0 with sustainable and adaptive practices enhances supply chain outcomes. Moreover, Farrukh et al. (2025) found that the adoption of Industry 4.0 technologies significantly enhances sustainable performance in the Pakistani food sector through green supply chain collaboration, circular

economy practices, and technological readiness. The study also showed that environmental dynamism positively moderates these relationships.

Similarly, Brookbanks and Parry (2024) found that implementing Industry 4.0 technologies, including IoT and blockchain, enhances resilience in cross-border supply chains by improving end-to-end visibility, information sharing, collaboration, trust, and integration. The study concluded that these technologies strengthen agility and adaptability, reducing operational decoupling between government agencies and supply chain participants. In a study by Pandey et al. (2025), it was found that integrating flexible supply chain practices with Industry 4.0 technologies enhances resilience and sustainability, enabling supply chains to better navigate disruptions such as pandemics, extreme weather, and political conflicts. The study concluded that combining flexibility with digital technologies empowers supply chains to respond faster to uncertainties and maintain operational continuity. In addition, the study by Jain et al. (2024) demonstrates that Industry 4.0 technologies help firms build supply chain resilience by enhancing supply chain visibility. The findings also show that environmental dynamism influences this relationship, with greater visibility enabling stronger resilience outcomes under varying environmental conditions.

### ***Research Gap***

Although existing studies consistently demonstrate that Industry 4.0 technologies enhance supply chain performance, integration, visibility, innovation, resilience, and sustainability (Fatorachian & Kazemi, 2021; Sharma et al., 2022; Khan & Emon, 2025; Zhu et al., 2022; Ghadge et al., 2020; Marinagi et al., 2023; Tortorella et al., 2024; Piprani et al., 2024; Farrukh et al., 2025; Brookbanks & Parry, 2024; Pandey et al., 2025; Jain et al., 2024), significant gaps remain in understanding these phenomena within food-processing firms, particularly in emerging economies such as Nigeria. While quantitative studies capture measurable impacts (such as improved operational efficiency, supply chain integration, digital collaboration, and sustainability outcomes), they largely overlook how managers interpret the meaning and relevance of Industry 4.0 within their own supply chain contexts, especially where infrastructural instability, energy constraints, fragmented supplier networks, and limited digital capabilities shape operational decision-making. Similarly, research on adoption and integration focuses on statistical relationships and mediating mechanisms, providing limited insight into the actual processes, challenges, and strategies used by food-processing firms to implement these technologies within resource-constrained and institutionally volatile environments.

Moreover, although performance improvements are well documented, little is known about managerial perceptions and lived experiences of operational efficiency gains, or how environmental, organisational, and cultural factors influence the gap between expected and realised benefits in contexts characterised by regulatory inconsistencies, skills shortages, and fluctuating macroeconomic conditions. Existing research highlights drivers, barriers, and resilience capabilities (Ghadge et al., 2020; Brookbanks & Parry, 2024; Jain et

al., 2024), but these are mostly sector-neutral or model-based, offering insufficient context-specific insights into the human, cultural, and organisational dynamics that shape technology implementation within Nigerian food-processing supply chains. In essence, this indicates a clear need for qualitative research to explore how managers perceive, adopt, integrate, and experience Industry 4.0, as well as how organisational and contextual factors shape the translation of anticipated benefits into operational realities in developing economy settings, thereby providing an empirically grounded rationale for the present study.

### ***Implementation of Industry 4.0 in Supply Chain Operations: Barriers and Enablers***

Implementation of Industry 4.0 in supply chain operations is shaped by both barriers and enablers, and authors explain these factors in different ways. Kumar et al. (2024) maintained that firms often struggle with high costs, low digital skills and weak infrastructure. Their work suggests that many food supply chains cannot adopt advanced tools because the basic systems they rely on are not strong enough. Derakhti et al. (2023) support this view and add that many agri-food supply chains face cultural resistance, poor training and limited management support. Zhao et al. (2024) give a more structured perspective. They find that infrastructure gaps and unclear regulations are the biggest barriers when firms try to use Industry 4.0 for sustainability. Their findings confirm that external conditions can slow down adoption even when firms are willing to change. Other authors focus more on the factors that enable successful adoption. Silva and Sehnem (2024) argue that stakeholder engagement works as a strong enabler because it helps firms align digital tools with circular-economy goals. Their work shows that technology produces real benefits only when all actors are involved.

Kaur et al. (2023) explain that visibility and efficiency increase when firms invest in basic digital tools such as sensors and data platforms. Their findings show that early-stage technologies can support adoption even when more advanced tools are not in place. Tascón and Mejía (2025) look at fresh-food supply chains in emerging countries. They find that firms can adopt some Industry 4.0 tools, although they often face challenges with logistics, skills and governance. Their work confirms that context affects how easily firms implement these technologies. Some studies give a more specific view of technical barriers. Perçin (2023) shows that poor data quality, weak analytics and limited system integration make it hard for agri-food firms to use big data. This point connects with the wider literature because it shows that technology fails when data is unreliable. Rahman et al. (2025) highlight financial limits and lack of workforce readiness as the most serious barriers in Bangladesh. Their findings match the concerns raised by Kumar et al. (2024) about cost and skills. These studies suggest that Industry 4.0 adoption depends on both internal and external conditions. The overall evidence shows that firms benefit when they invest in skills, data and stakeholder involvement. The evidence also shows that adoption slows down when cost, infrastructure and regulatory gaps remain unresolved.

## Methodology

### *Research Philosophy and Approach*

This study adopted an interpretivist philosophy because it aimed to understand how managers interpret and make meaning of Industry 4.0 technologies in food-processing supply chains. Interpretivism is appropriate when research focuses on subjective experiences, perceptions, and interpretations, rather than testing causal relationships or measuring objective variables (William, 2024). In line with this philosophy, an exploratory qualitative approach was adopted to generate rich, nuanced insights into a phenomenon that remains under-theorised in Nigerian food-processing firms (Turin et al., 2024). An inductive approach guided data analysis, allowing patterns, themes, and insights to emerge from the participants' accounts rather than testing pre-existing hypotheses.

### *Research Design*

A phenomenological design was employed to explore the lived experiences of supply chain managers with Industry 4.0 adoption. This design is well-suited to capture how participants perceive, interpret, and enact new technologies within their organisational context (Van Manen, 2023). A cross-sectional time horizon was adopted, with data collected over a short period to examine current experiences and perceptions without tracking changes over time (Maier et al., 2023).

### *Sample and Sampling Technique*

The study recruited 10 experienced supply chain managers from food-processing firms in Calabar, Cross River State, Nigeria. Participants included 7 top-level executives and 3 mid-level departmental heads, combining strategic decision-making and operational perspectives. The firms represented a range of industries, including agro-processing, meat and seafood processing, bakeries/snack manufacturers, food preservation/packaging companies, and small-scale traditional food-processing businesses. Company sizes ranged from small enterprises (less than 50 employees) to medium and large firms (up to 250 employees). Purposive and snowball sampling were used to select participants with direct experience of Industry 4.0 implementation. Purposive sampling ensured participants had at least three years of relevant managerial experience, while snowball sampling facilitated access to hard-to-reach networks, enhancing the richness and credibility of the data.

### *Data Collection Procedure and Interview Guide*

Data were collected using semi-structured interviews, conducted electronically and recorded for transcription. Semi-structured interviews were chosen to allow participants to explain their experiences in detail while enabling the researcher to maintain focus on the study's four research objectives:

- i. Exploring how managers interpret the meaning and relevance of Industry 4.0,
- ii. Investigating adoption and integration processes,
- iii. Understanding managerial perceptions of operational impacts, and

- iv. Analysing organisational, cultural, and contextual factors shaping the gap between anticipated and actual benefits.

The interview guide was structured around these objectives, covering domains such as: interpretations of Industry 4.0, decision-making processes for adoption, integration challenges, perceptions of operational efficiency, cultural and leadership influences, and external pressures affecting implementation. Follow-up questions and probes were used to clarify responses and uncover deeper insights.

### ***Ethical Consideration***

Ethical approval was obtained from the Faculty of Administration and Management, University of Calabar, Nigeria, ensuring adherence to institutional standards for research involving human participants. Participants provided informed consent after being briefed on the study's purpose, the voluntary nature of participation, and their right to withdraw at any time. Participant anonymity was maintained through pseudonymisation in transcripts and reporting. Confidentiality was ensured by storing recordings and transcripts securely, with access restricted to the research team. The use of electronic interviews was justified ethically, as it allowed participants to respond in a private, convenient setting while reducing disruption to work routines.

### ***Data Analysis and Trustworthiness***

Interviews were transcribed verbatim and analysed using Braun and Clarke's (2006) reflexive thematic analysis (RTA). This method enabled systematic identification of patterns of meaning while supporting a reflexive, iterative process, allowing the researcher to acknowledge personal interpretations and positionality. To enhance credibility, findings were triangulated with multiple participants and cross-checked against the literature. Dependability was addressed through audit trails, documenting decisions during data collection and coding. Transferability was facilitated by providing detailed descriptions of participants, firm types, and contexts. Confirmability was achieved by reflexive journaling, enabling awareness of potential biases and ensuring that themes emerged from participants' accounts rather than researcher preconceptions (Morriss, 2024; Ahmed et al., 2025). Data saturation was reached by the tenth interview, as no new themes emerged, confirming that the sample size was sufficient to address the research objectives.

### ***Analysis and Discussion***

The data obtained from the interview were thematically analysed in line with the research objectives in order to ensure a structured and focused interpretation of participants' accounts, allowing the study to generate clear, objective-driven insights into how Industry 4.0 is understood, adopted, and experienced within food-processing supply chains. Among the 10 participants interviewed, 7 were top supply chain executives, while 3 were mid-level supply chain departmental heads. This entails that the views generated in the study were

drawn predominantly from senior decision-makers who directly influence strategic adoption of Industry 4.0, while also incorporating perspectives from mid-level managers who oversee day-to-day operational implementation. This blend of strategic and operational insights strengthened the depth of the analysis by ensuring that interpretations of Industry 4.0 reflected both high-level organisational priorities and the practical realities of integrating new technologies within food-processing supply chains.

**Objective one:** To explore how food-processing firms interpret the meaning and relevance of Industry 4.0 within their supply chain operations

### ***Theme 1: Industry 4.0 as a Symbol of Innovation and Modernisation***

Participants consistently interpreted Industry 4.0 as a marker of technological progress, even when implementation remained limited. This interpretation reflects sensemaking processes, where managers construct meaning by linking Industry 4.0 with organisational aspirations rather than operational realities (Weick, 1995).

Participant 3 explained:

*"For us, Industry 4.0 simply means modernising; using anything digital to stay competitive. We may not have advanced systems yet, but the idea motivates us to upgrade gradually."*

Participant 7 added:

*"When leadership talks about Industry 4.0, they mostly mean keeping up with global trends. It's more of a strategic direction than a concrete technology plan at this stage."*

This emphasis on innovation mirrors Farrukh et al. (2025), who argue that digitalisation is increasingly viewed as a route to competitiveness and long-term sustainability. However, Sharma et al. (2022) caution that conceptual enthusiasm often exceeds practical readiness; precisely what interview data reveal. Through the TOE lens, technological readiness and organisational culture strongly shaped these interpretations. Firms with higher digital maturity attached more concrete meaning to Industry 4.0, whereas those with weaker infrastructure viewed it aspirationally. This variation aligns with Zhu et al.'s (2022) assertion that technology only achieves value when organisational processes and capabilities align.

### ***Theme 2: Industry 4.0 as a Tool for Increasing Traceability and Visibility***

A second dominant interpretation positioned Industry 4.0 as a mechanism for improving product traceability, particularly critical in the food sector.

Participant 1 emphasised:

*"For us, the biggest relevance is being able to track raw materials and finished goods. Even small digital tools help us reduce errors and meet safety requirements."*

Participant 9 echoed this, saying:

*"Traceability is where we see Industry 4.0 being most useful. Customers ask for transparency, and regulators demand it. Digital systems make it easier."*

These interpretations align with Jain et al. (2024) and Riaz et al. (2025), who highlight visibility and traceability as core benefits of Industry 4.0, especially in environments with

high perishability. The data also support Khan and Emon (2025), who argue that technologies such as IoT and analytics strengthen visibility and process integration. From a sensemaking perspective, managers drew meaning from sector-specific pressures (including regulation, perishability, customer expectations), which shaped how they interpret relevance. The environmental context within the TOE framework further reinforces this interpretation, as firms operate in regulatory environments where visibility is non-negotiable.

**Theme 3: Industry 4.0 as a Pathway to Operational Efficiency—But with Cautious Optimism**

While managers associated Industry 4.0 with efficiency, interpretations were often tempered by concerns about infrastructure, skills, and readiness.

Participant 2 noted:

*"Yes, Industry 4.0 can improve efficiency, but we are still dealing with basic automation gaps. It's relevant, but we need to start with simple systems first."*

Participant 5 similarly stated:

*"The idea is good—less waste, faster processes—but without the right skills it becomes difficult. So, its relevance is there, but limited by our realities."*

These perspectives reflect Sharma et al. (2022), who emphasise that Industry 4.0 generates performance improvements only when embedded into organisational processes. They also align with Marinagi et al. (2023), who argue that perceived efficiency often precedes actual efficiency, especially in firms with low digital maturity. Critically, managers' cautious optimism demonstrates how sensemaking is shaped by constraints. As Weick (1995) argues, people make sense of new phenomena by integrating expectations with lived conditions. Here, interpretations remain aspirational because organisational readiness is low, consistent with TOE's organisational dimension.

**Theme 4: Industry 4.0 as a Context-Dependent and Culturally Shaped Concept**

Interpretations were not universal; they varied depending on leadership orientation, organisational culture, and managerial experience.

Participant 10 reflected:

*"Our leadership is conservative, so Industry 4.0 is seen as something 'for the future'. That affects how employees understand it—we don't see it as urgent."*

Participant 6 contrasted this:

*"We are encouraged to experiment with digital tools. That culture makes Industry 4.0 feel relevant and achievable."*

This divergence supports Brookbanks and Parry (2024), who show that digital transformation relies heavily on collaboration and organisational openness. It also echoes Pandey et al. (2025), who argue that digital adoption is shaped by cultural readiness and flexibility. In TOE terms, the organisational context (culture, leadership, capabilities) acts

as a decisive filter through which Industry 4.0 is interpreted. Through sensemaking, managers translate organisational cues into meaning, explaining why the same technologies generate different interpretations across firms.

Across all interviews, managers did not interpret Industry 4.0 as a singular, well-defined concept. Instead, they made sense of it through four lenses (innovation, visibility, efficiency, and culture), each shaped by organisational readiness, environmental pressures, and technological constraints. These interpretations reveal that Industry 4.0's meaning is constructed, negotiated, and context-specific, supporting Weick's (1995) view that organisations create meaning through social processes rather than through the technologies themselves. The findings further align with the TOE framework by showing that firms' interpretations are influenced by technological maturity, organisational culture, and environmental expectations, demonstrating that relevance is framed as much by context as by capability.

**Objective two:** To critically explore how Industry 4.0 technologies are adopted and integrated into the supply chain processes of food-processing firms.

#### ***Theme 1: Incremental and Reactive Adoption***

A dominant pattern across participants was that Industry 4.0 adoption is largely incremental, with firms implementing technologies in phases, often in response to immediate operational needs rather than strategic planning.

Participant 1 stated:

*"We start small—adding sensors on critical machines, linking a few data points to monitor production. It's not a full rollout. Usually, something breaks or a problem occurs, and then we try to fix it digitally."*

Participant 4 explained:

*"Integration happens in steps. Our ERP system is partially connected to production lines, and some departments still rely on spreadsheets. Adoption is reactive—we add digital tools when pressure mounts from regulators or customers."*

This observation aligns with Sharma et al. (2022), who argue that technologies alone do not improve performance; effective integration into operational processes is critical. It also reflects sensemaking theory, as managers interpret and act on technologies based on pressing issues, constructing meaning through ongoing experiences (Weick, 1995). In TOE terms, the technological and organisational readiness of firms constrains proactive adoption, while external pressures (environment) trigger incremental uptake (Tornatzky & Fleischer, 1990).

#### ***Theme 2: Integration Challenges Across Functional Areas***

Managers highlighted that even when technologies are adopted, integration across production, inventory, logistics, and quality control is uneven, often resulting in siloed implementation.

Participant 6 elaborated:

*"We have IoT sensors tracking storage temperatures, but production schedules are still manually recorded. Connecting these systems has been slow because different teams use different platforms, and not all understand how to link them."*

Participant 9 added:

*"Blockchain is being piloted for traceability in raw materials. But the integration with our ERP and distribution systems is partial. Our IT team struggles to get real-time data from suppliers, so benefits are limited."*

These insights support Khan and Emon (2025), who emphasise that technologies such as IoT, AI, and Big Data improve real-time monitoring and coordination only when properly integrated. Marinagi et al. (2023) also note that partial integration limits the development of resilient and responsive supply chains, underscoring the need for systemic adoption. The TOE framework explains this as a function of organisational and technological factors, including digital skills, legacy systems, and internal process alignment.

#### *Theme 3: Selective Adoption Based on Perceived Value*

Managers reported that adoption decisions are guided by perceived relevance and expected returns, resulting in selective implementation rather than blanket digitalisation.

Participant 3 observed:

*"We invested in AI for predictive maintenance because machine downtime directly affects output. But advanced analytics for forecasting demand across distribution networks is still under consideration because the cost and complexity are high."*

Participant 7 reflected:

*"Digital traceability for export products was prioritised. Internal reporting systems are next. We make choices based on what will give visible improvements quickly, and what regulators demand first."*

These perspectives reflect Fatorachian and Kazemi (2021), who argue that the benefits of Industry 4.0 are multi-dimensional, spanning efficiency, visibility, resilience, and sustainability. Adoption is therefore guided by strategic prioritisation. Sensemaking theory explains this selective approach: managers construct meaning from expected operational gains, and act where benefits are tangible (Weick, 1995). In TOE terms, organisational capabilities and environmental pressures jointly determine which technologies are adopted first (Tornatzky & Fleischer, 1990).

#### *Theme 4: Barriers to Full Integration*

A recurring theme was that financial constraints, low digital skills, and legacy systems limit both adoption speed and full integration.

Participant 2 explained:

*"We want to link all our production, warehouse, and logistics data, but our ERP is outdated. Hiring IT specialists is expensive, and training production staff takes time. Full adoption feels like a long-term goal."*

Participant 8 added:

*"Even when we purchase advanced systems, the lack of digital literacy among employees slows integration. Many still rely on manual checks, so the digital tools are underutilised."*

This echoes Ghadge et al. (2020) and Zhu et al. (2022), who show that technology adoption alone does not guarantee improved performance; organisational readiness, human resources, and infrastructural support are critical. Sensemaking theory complements this by highlighting that managers interpret technologies within the constraints of existing capabilities, making adoption cautious and phased (Weick, 1995).

Essentially, the findings reveal that Industry 4.0 adoption in food-processing supply chains is incremental, selective, and context-driven, shaped by organisational readiness, perceived operational value, and external pressures. Technologies are rarely fully integrated, often applied in siloed or reactive ways, and adoption is mediated by infrastructure, skills, and financial constraints. Sensemaking theory explains how managers interpret and act on technologies according to practical needs and organisational realities, while the TOE framework shows how technological, organisational, and environmental factors interact to enable or constrain adoption. Collectively, these insights underscore that effective integration requires strategic planning, alignment of systems, investment in skills, and responsive organisational structures, rather than simply purchasing digital tools.

**Objective three:** To understand how managers experience and perceive the impact of Industry 4.0 technologies on operational efficiency

#### ***Theme 1: Enhanced Monitoring and Real-Time Decision-Making***

From the interview, managers consistently reported that Industry 4.0 technologies improved their ability to monitor operations in real time, supporting faster and more informed decision-making.

Participant 1 stated:

*"With IoT sensors on production lines, we can see immediately if a machine is overheating or a batch is delayed. Decisions can be made on the spot rather than waiting for end-of-day reports."*

Participant 5 added:

*"AI dashboards give us predictive insights. We can adjust schedules or resource allocation almost instantly. This wasn't possible before digital tools."*

These accounts align with Khan and Emon (2025), who highlight that IoT, AI, and Big Data Analytics enhance operational coordination and reduce errors. Similarly, Marinagi et al. (2023) note that such technologies strengthen resilience and responsiveness by allowing proactive responses to disruptions. From a TOE framework perspective, these benefits arise because the technological dimension (availability of sensors and analytics) interacts with organisational routines that allow managers to act on real-time data, while environmental pressures (such as consumer demand for speed and quality) reinforce the need for rapid decision-making (Tornatzky & Fleischer, 1990).

***Theme 2: Operational Efficiency Gains***

Participants highlighted concrete improvements in throughput, reduced errors, and process standardisation following Industry 4.0 adoption.

Participant 3 remarked:

*"We have reduced batch errors by 30% since introducing automated tracking and quality checks. Employees can focus on managing exceptions rather than repetitive manual work."*

Participant 8 shared:

*"Production cycles are more consistent. Inventory management has improved because digital tools flag shortages before they affect operations."*

This perspective resonates with Sharma et al. (2022), who emphasise that Industry 4.0 mediates supply chain practices and performance outcomes. Fatorachian and Kazemi (2021) similarly argue that digital tools enhance transparency and process efficiency, improving operational performance. Sensemaking theory explains how managers perceive these improvements: managers construct meaning around observed performance gains, validating the usefulness of technologies in real operational contexts (Weick, 1995).

### *Theme 3: Mixed Experiences Due to Integration and Skills Gaps*

Despite benefits, managers noted that efficiency gains are uneven, depending on technology integration, employee digital skills, and process alignment.

Participant 2 observed:

*"The systems are helpful, but when departments don't fully integrate or staff are unsure how to use them, benefits are limited. Sometimes digital tools exist but are underused."*

Participant 7 added:

*"We have predictive maintenance, but production staff often ignore alerts because they don't fully trust the system. Efficiency gains depend on training and confidence."*

These insights echo Zhu et al. (2022), who caution that technology adoption does not automatically improve performance without alignment and integration. TOE theory explains this as an interaction between the technological infrastructure, organisational capability (training, process adaptation), and environmental pressure to maintain efficiency (Tornatzky & Fleischer, 1990). Sensemaking theory reinforces those managerial perceptions are shaped not only by the technology but by how it is interpreted and enacted within existing routines (Weick, 1995; Saeed et al., 2024).

Essentially, the data shows that managers experience Industry 4.0 as a double-edged enabler of operational efficiency. Where technologies are well-integrated, aligned with workflows, and supported by skilled staff, they improve monitoring, reduce errors, and enable rapid decisions, enhancing throughput and consistency. Conversely, partial adoption, siloed systems, and low digital literacy can limit realisation of these benefits, creating mixed perceptions of value. Sensemaking theory explains that managers' experiences are shaped by interpretation of technology within context, while the TOE framework shows that operational efficiency gains depend on the interaction of technological, organisational, and environmental factors. The analysis demonstrates that realising full operational benefits requires systematic integration, workforce capability

development, and alignment of digital tools with organisational processes rather than piecemeal implementation.

**Objective four:** To critically analyse the organizational, cultural, and contextual factors that shape the gap between the anticipated benefits and actual realities of Industry 4.0 implementation in food-processing firms

For objective four, findings indicate that while managers recognize the transformative potential of Industry 4.0, its realization is heavily mediated by internal capabilities, leadership orientation, and external pressures, reflecting the interplay of the TOE framework (Tornatzky & Fleischer, 1990) and sensemaking processes (Weick, 1995).

### ***Theme 1: Organizational Readiness and Digital Maturity***

Managers repeatedly highlighted that limited infrastructure and uneven technological maturity constrain meaningful adoption. Participant 2 noted:

*"We invested in IoT sensors and AI tools, but the legacy ERP systems cannot fully communicate with these platforms. So, a lot of the expected efficiencies just don't materialize."*

This aligns with Kumar et al. (2024) and Zhao et al. (2024), who argue that internal technological readiness is critical. TOE's organizational dimension explains this: even with strong technological solutions available, performance depends on firm-specific resources, integration capabilities, and internal processes (Chittipaka et al., 2023). Sensemaking theory complements this, showing that managers actively interpret these limitations when evaluating the relevance and feasibility of Industry 4.0 adoption (Weick, 2021; Saeed et al., 2024).

### ***Theme 2: Cultural Orientation and Leadership***

The study revealed that managerial interpretations and adoption patterns are strongly influenced by corporate culture and leadership engagement. Participant 6 reflected:

*"Some teams see digitalisation as extra work rather than an opportunity. Leaders need to guide and motivate employees to adopt these technologies, otherwise we hit resistance at every step."*

This confirms Derakhti et al. (2023) and Tascón and Mejía (2025), who observe that cultural resistance and weak leadership slow integration. Sensemaking theory explains how managers construct meaning around technologies; differing interpretations across hierarchical levels can either bridge or widen the gap between expected and actual benefits (Weick, 1995; Nyström, 2024).

### ***Theme 3: Contextual Constraints and External Pressures***

Regulatory complexity, supply chain fragmentation, and environmental volatility also shape outcomes. Participant 9 stated:

*"Even when we implement blockchain for traceability, inconsistent supplier compliance and shifting food safety regulations mean the full potential of the system isn't realized."*

This supports findings by Zhao et al. (2025) and Brookbanks and Parry (2024), highlighting how contextual and environmental factors influence operational effectiveness. TOE's environmental dimension captures these pressures, emphasizing that external rules, market volatility, and supplier readiness are critical determinants of success (Tornatzky & Fleischer, 1990; Chittipaka et al., 2023).

#### **Theme 4: Interaction Between Anticipation and Reality**

Across participants, the study found a recurrent pattern: anticipated benefits, such as efficiency, traceability, and operational agility, are partially achieved but often modified by real-world constraints. Participant 4 explained:

*"We expected AI-driven forecasting to cut waste by 30%, but integration delays and skill gaps meant we only achieved around 10%. The technology works, but not as we imagined."*

This finding underscores the multi-dimensional nature of Industry 4.0 (Farrukh et al., 2025; Marinagi et al., 2023), where operational efficiency, collaboration, and strategic outcomes interact dynamically. Sensemaking theory clarifies how managers reconcile discrepancies between expectation and reality, interpreting partial successes, negotiating trade-offs, and adjusting strategies (Weick, 1995; Saeed et al., 2024).

Collectively, the data show that the gap between anticipated and actual benefits is not merely technological but arises from a complex interplay of organizational readiness, culture, leadership, and external pressures. TOE provides a structured lens to map these factors across technological, organizational, and environmental dimensions (Tornatzky & Fleischer, 1990; Chittipaka et al., 2023). Sensemaking theory offers a complementary view, emphasizing that managers' interpretations of these factors actively shape adoption outcomes (Weick, 1995, 2021; Nyström, 2024). The findings suggest that closing this gap requires a holistic approach: aligning internal capabilities, fostering supportive culture, developing leadership engagement, and adapting strategies to contextual realities. The study thereby moves beyond measuring performance gains to understanding the human and organizational processes that translate the "hype" of Industry 4.0 into operational reality.

#### **Discussion of Findings**

The first objective explored how food-processing firms interpret the meaning and relevance of Industry 4.0. Findings show that managers view Industry 4.0 as a symbol of innovation and modernisation, a tool for traceability, and a potential route to operational efficiency, though these interpretations are strongly shaped by organisational culture and technological readiness. Firms with higher digital maturity attached concrete meaning to Industry 4.0, while less prepared firms viewed it aspirationally. These results demonstrate that sensemaking processes (Weick, 1995) are central to understanding managerial perceptions, while the TOE framework highlights how technological, organisational, and environmental factors influence how relevance is construed. The findings extend prior

literature by showing that interpretations are context-specific and mediated by both aspiration and practical constraints.

The second objective examined how Industry 4.0 technologies are adopted and integrated into supply chain processes. Adoption is largely incremental, selective, and reactive, with firms implementing technologies in phases to address immediate operational challenges. Integration across functional areas is uneven, often resulting in siloed applications. Managers prioritise technologies that offer tangible returns, such as predictive maintenance or digital traceability, reflecting both perceived value and external pressures. Sensemaking theory explains this selective adoption as managers act based on what they perceive will generate meaningful operational gains, while TOE highlights that technological readiness, organisational capability, and environmental pressures jointly constrain adoption. These findings challenge the assumption in some performance-focused studies that technology alone drives improvement.

The third objective focused on managers' experiences of Industry 4.0 on operational efficiency. Participants reported real benefits in monitoring, decision-making, and error reduction when technologies were integrated and supported by trained staff. However, efficiency gains were uneven due to partial adoption, skills gaps, and siloed systems, producing mixed experiences. Sensemaking theory clarifies that managers interpret and validate technology benefits within the context of organisational routines, while the TOE framework situates these outcomes in the interaction between technological infrastructure, organisational processes, and environmental demands. The findings indicate that realising operational efficiency requires systematic integration, workforce capability development, and alignment of technologies with business processes.

The fourth objective explored organisational, cultural, and contextual factors shaping the gap between anticipated and actual benefits. Limited infrastructure, leadership engagement, cultural orientation, and regulatory pressures moderated the extent to which expected advantages were realised. Managers actively reconciled the difference between expectation and reality, negotiating trade-offs and adapting strategies. Combining sensemaking and TOE frameworks demonstrates that the gap is not only technological but socio-organisational: human interpretation, culture, and contextual factors critically determine outcomes. Practically, closing this gap requires holistic strategies that align internal capabilities, foster supportive culture, and adapt adoption plans to real-world constraints, moving beyond hype towards sustainable operational impact.

## Conclusion

This study examined how Nigerian food-processing firms interpret, adopt, and integrate Industry 4.0 technologies within their supply chain operations, while exploring managerial experiences and the organisational, cultural, and infrastructural factors shaping the gap between anticipated benefits and operational realities. In line with the study's objectives, findings show that managers interpret Industry 4.0 as a marker of innovation, a tool for traceability, and a pathway to operational efficiency, but interpretations vary depending on

leadership orientation, organisational culture, and technological readiness. Adoption is largely incremental, selective, and reactive, constrained by financial, skills, and infrastructure limitations, with uneven integration across functional areas. Managers reported that operational efficiency gains, through faster decision-making, reduced errors, and improved throughput, occur primarily when technologies are aligned with processes, supported by skilled staff, and integrated across the supply chain, highlighting the conditional nature of Industry 4.0 outcomes.

The study makes a theoretical contribution by combining sensemaking theory (Weick, 1995; 2021) and the TOE framework (Tornatzky & Fleischer, 1990). Sensemaking explains how managers actively construct meaning from ambiguous technological innovations, accounting for divergent interpretations and adoption decisions, while TOE situates these behaviours within technological, organisational, and environmental constraints. This dual-framework approach demonstrates that understanding Industry 4.0 adoption requires both attention to managerial cognition and the organisational context, moving beyond prior quantitative or model-based studies that focus solely on performance metrics or adoption rates. It shows that the gap between anticipated and actual benefits arises from the interaction of human, organisational, and environmental factors rather than technology alone.

Practically, the study highlights that Industry 4.0 should be treated as a context-sensitive transformation process rather than a purely technological upgrade. Firms with stronger infrastructure, leadership engagement, and workforce capabilities are better able to realise efficiency, visibility, and resilience gains, whereas low digital maturity, fragmented supply chains, and regulatory volatility limit outcomes. The findings underscore the need for strategic alignment, skills development, and supportive culture to bridge the gap between expectation and reality. Overall, this research consolidates both empirical and theoretical contributions, providing actionable insights into how Nigerian food-processing firms can translate the “hype” of Industry 4.0 into operational reality while advancing understanding of the interplay between managerial sensemaking and organisational context.

### **Recommendations and Practical Implications**

Based on the findings of this study, the following recommendations are suggested:

1. Food-processing firms should conduct comprehensive readiness assessments before implementing Industry 4.0 technologies, ensuring that infrastructure, workforce skills, and processes are sufficiently mature to support digital tools. Practically, this means investing in basic digital infrastructure such as IoT-enabled sensors, integrated ERP systems, and cloud-based platforms to enable real-time data collection and decision-making. Such alignment ensures that technological adoption translates into meaningful operational improvements rather than remaining superficial or underutilized.

2. Given the identified skill gaps, food-processing firms should implement targeted training programmes to build employees' digital competencies and familiarity with Industry 4.0 tools. In practice, this can involve workshops on AI-driven analytics, predictive maintenance, and blockchain-based traceability, enabling managers and staff to effectively interpret and leverage digital insights for supply chain optimisation. Skilled personnel increase adoption confidence, reduce resistance, and facilitate smoother integration of new technologies.
3. Digital tools are most effective when aligned with supply chain partners, including suppliers, distributors, and regulatory bodies. Practically, firms should establish communication protocols and collaborative platforms for data sharing, traceability, and joint planning, which enhances visibility, operational coordination, and resilience. Engagement across the network reduces silos, ensures compliance, and strengthens collective responsiveness to disruptions.
4. Rather than attempting full-scale, simultaneous deployment, food-processing firms should adopt phased Industry 4.0 integration tailored to their specific operational contexts. In practice, this involves piloting technologies in selected processes, evaluating performance, and scaling gradually while considering regulatory, cultural, and infrastructural constraints. Incremental adoption allows firms to manage costs, build internal capabilities, and adapt tools to real-world challenges.
5. Managers should explicitly design supply chain processes to leverage digital technologies for both efficiency and resilience. Practically, this means using predictive analytics, AI, and digital twins to anticipate disruptions, optimise inventory, and adjust production schedules dynamically, thus ensuring continuity in volatile food-processing environments.
6. Government agencies, industry associations, and regulatory bodies should support Industry 4.0 adoption through stable regulatory frameworks, incentive structures for digital investment, and national digital readiness programmes for SME food processors. Practically, this could include providing subsidies or tax incentives for technology adoption, standardising compliance requirements, and offering guidance on integrating digital tools to meet food safety and quality standards. Such interventions reduce regulatory uncertainty, promote consistency across the sector, and enable firms to adopt Industry 4.0 technologies more confidently and effectively.

Essentially, these recommendations underscore the need for a strategically aligned, context-aware, and human-centric approach to Industry 4.0 adoption, bridging the gap between anticipated benefits and operational realities. By combining technological readiness with managerial sensemaking and organizational adaptation, food-processing firms can translate Industry 4.0 from conceptual hype into measurable operational and strategic gains.

### Limitations and Further Studies

This study has several limitations that should be acknowledged. First, the sample was limited to ten supply chain managers from food-processing firms in Calabar, Cross River State, which constrains the transferability of findings even within Nigeria and limits generalisation to other emerging economies. While the qualitative design provided rich, in-depth insights, it does not permit statistical inference or quantification of the impact of Industry 4.0 technologies. Second, the study relied on self-reported perceptions and experiences, which may be influenced by recall bias, social desirability, or subjective interpretation, despite efforts to enhance credibility through careful interview design and thematic analysis. Third, the cross-sectional design captures only a snapshot of adoption and implementation within Nigeria's volatile operating environment, without examining how firms' Industry 4.0 practices evolve amid infrastructural, economic, and regulatory fluctuations. Finally, the researcher's positionality may have influenced the interpretation of interview data and theme development, a recognised limitation of reflexive thematic analysis, even with systematic coding and peer review.

Future research could address these limitations by employing larger, multi-state, or cross-country samples to strengthen external validity and enable comparative analysis across emerging and developed economies. Longitudinal studies could trace implementation trajectories and shifting managerial interpretations of Industry 4.0 over time. Additionally, mixed-method approaches combining qualitative interviews with quantitative performance indicators could provide a more comprehensive understanding of how Industry 4.0 adoption translates into operational and strategic outcomes in resource-constrained settings. Further studies could also investigate Nigeria-specific contextual factors, including energy reliability, foreign exchange volatility, regulatory enforcement, informal supplier networks, and digital readiness, to clarify how these elements shape adoption gaps and realised benefits.

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