

THE EVOLUTION OF SMART INVENTORY MANAGEMENT: INTEGRATING AI, IoT and LLMs INTO DYNAMIC CAPABILITIES

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Abstract

This paper evaluates how inventory-management technologies have developed over the last decade (2014-2024) and records the transformation of the traditional ERP-focused models to complex cognitive ecosystems. It aims at establishing the technological synergies and also solving the Emerging Market Paradox, wherein infrastructure shortages hinder the adoption of Industry 4.0 in countries like Nigeria. A Systematic Literature Review (SLR) was performed based on PRISMA 2020. Using thematic synthesis, 57 high-quality peer-reviewed articles and authoritative market reports were synthesized in order to map the technological pathways and barriers to adoption. The findings show that there is a four-step evolutionary migration, (1) Foundational Integration, (2) Real-time Visibility through IoT, (3) Predictive AIAnalytics and (4) The Cognitive Frontier (LLMs and Digital Twins). Although AI and LLMs are transformative in offering Actionable Insights, a major SME Barrier exists in emerging markets because capital intensity is high, there is a deficit in infrastructure, and cognitively skilled labor is scarce. The paper presents the Integrated Smart Inventory Ecosystem (ISIE) model that operationalizes the Resource-Based View (RBV) to integrate separate technologies into a Dynamic Capability. This framework is an implementation roadmap that is staged and highly modular, and which is specifically designed to fit into resource-constrained environments, thus closing the gap between a high-level theory and emerging market realities.

Keywords: Industry 4.0, Smart Inventory Management, ERP, IoT, Artificial Intelligence (AI), Large Language Models (LLMs), Resource-Based View (RBV), Emerging Markets.

Introduction

Inventory management has evolved from a routine operational activity into a strategic component of supply-chain resilience in the industry 4.0 era. Organizations increasingly rely on digital technologies such as ERP, IoT, AI, and predictive analytics to improve inventory visibility, responsiveness, and decision-making under uncertain market conditions. The global smart inventory management market is expanding rapidly, driven by the adoption of Enterprise Resource Planning (ERP), Internet of Things (IoT), Artificial Intelligence (AI), and related Industry 4.0 technologies (Allied Market Research, 2024; Fang, 2024; Zhu et al., 2023). More recently, Large Language Models (LLMs) have enhanced data interpretation and decision support through natural-language interaction with inventory systems (Chowdhury, 2025).

Despite growing investment in digital supply-chain technologies, existing studies largely examine ERP, RFID, IoT, AI, and LLMs in isolation rather than as an integrated inventory management ecosystem. Limited attention has also been given to how these technologies interact to build supply-chain resilience, particularly within resource-constrained and emerging-market contexts. To address these gaps, this study

synthesises academic literature and industry evidence published between 2014 and 2024 to examine the evolution, benefits, barriers, and integration of Industry 4.0 technologies in inventory management.

However, there is still a major knowledge-action gap. Although Gartner (2024) states that 80% of CEOs plan to invest more in digital, academic literature is still isolated. The majority of research is on the technical mechanics of an individual tool ecosystem (Zhang et al., 2025; Safinaz & Al-Zoubi, 2024; Rolando, 2024), e.g., RFID accuracy, without considering the synergistic assembly of these tools into a single. This paper fills these gaps by synthesizing a decade of academic findings (2014-2024) and real-world market intelligence to postulate an extensive global trend analysis and address the following research question:

- i. How are Industry 4.0 technologies transforming inventory management practices globally?
- ii. What benefits, challenges, and strategic synergies arise from the adoption of these technologies in inventory management systems?

The study contributes to the growing Industry 4.0 literature by providing a consolidated perspective on smart inventory management trends, technological synergies, implementation barriers, and implications for organisational resilience.

Literature Review

The Taxonomy of Inventory Technologies

The shift towards smart inventory management is not just a simple technological upgrade, but a multidimensional process, the intersection of a variety of digital layers. The Foundational Layer is at the centre of this transformation, and it is mainly dominated by Enterprise Resource Planning (ERP) systems. Although ERP systems remain foundational to smart inventory management by enabling cross-functional data integration (Acar et al., 2018), recent studies argue that their strategic value increasingly depends on interoperability with real-time technologies such as IoT and AI (Pontoh et al., 2024). This suggests that ERP systems alone are no longer sufficient for achieving supply-chain agility in Industry 4.0 environments.

Existing literature consistently identifies IoT and RFID as critical enablers of real-time inventory visibility and automation (Manavalan & Jayakrishna, 2019; Tan & Sidhu, 2022). However, while studies emphasize operational efficiency gains, there is less consensus regarding scalability and cybersecurity readiness, particularly in SMEs and emerging economies where infrastructure limitations remain significant.

Recent studies position AI as a major driver of predictive inventory optimization through demand forecasting and anomaly detection (Teixeira et al., 2025). However, much of the literature remains conceptual, with limited empirical evidence on the integration of AI and LLMs into legacy ERP environments. Similarly, although LLMs are increasingly discussed as decision-support tools, their practical implementation in live inventory ecosystems remains underexplored.

Collectively, the literature demonstrates a gradual shift from isolated technology adoption toward integrated digital ecosystems. Earlier studies focused primarily on ERP-driven coordination and RFID-enabled visibility, whereas more recent research emphasises AI-enabled prediction and cognitive decision support. Nevertheless, the literature remains fragmented, with limited studies examining how these technologies interact collectively to enhance inventory resilience and strategic capability.

Theoretical Framework

The paper is grounded on the Resource-Based View (RBV) of competitive advantage, which focuses on the exploitation of valuable, rare, inimitable, and non-substitutable technological resources to attain competitive advantage (Wernerfelt, 1984; Barney, 1991), and Systems Theory, which highlights the interdependence and coordination of the components of a system to deliver optimal performance

(Pontoh et al., 2024; Manavalan & Jayakrishna, 2019). Integrating these two theoretical approaches, the framework identifies the strategic importance of technology as an organizational resource and the need to harmonize interactions between components of a system. While RBV explains how digital technologies can create competitive advantage through valuable and difficult-to-imitate capabilities, Systems Theory provides a complementary perspective by emphasizing interdependence and coordination among technological components. The integration of both theories is particularly relevant in Industry 4.0 environments, where organizational performance depends not only on the possession of technological resources but also on their effective integration across inventory systems.

Methodology

Research Design

The study adopted a Systematic Literature Review (SLR) guided by PRISMA 2020 to synthesize evidence on the integration of Industry 4.0 technologies in inventory management. The SLR approach was selected to ensure a transparent, rigorous, and replicable review of both academic studies and relevant industry evidence published between 2014 and 2024.

Search Strategy and Data Sources

In order to cover the technological trajectory between 2014 and 2024, a systematic search was performed in four major academic databases, which are Scopus, Web of Science, ScienceDirect, and Google Scholar. Industry reports from Gartner, Statista, and Allied Market Research were included because Industry 4.0 technologies evolve rapidly, and some recent adoption trends may not yet be fully represented in peer-reviewed literature. The search terms were used with Boolean operators to combine the essential concepts: (Inventory Management) or (Stock Control) and (Industry 4.0) or (Digital Transformation) and (ERP) or (IoT) or (RFID) or (AI) or (LLM). To ensure the search was relevant in time, the past ten years (only) were considered, which included the emergence of the Smart Warehouse concept.

Selection Criteria and Quality Assessment

Studies were screened using predefined inclusion and exclusion criteria. Eligible studies included peer-reviewed and reputable industry publications addressing Industry 4.0 technologies in inventory management. Non-scholarly articles, unverifiable reports, or studies lacking transparency in the methodology were excluded. Quality assessment focused on methodological transparency, relevance to inventory management, and clarity of empirical or conceptual contributions.

Study Selection Process (PRISMA Application)

The PRISMA screening process (Figure 1) identified 98 initial records. After removing 12 duplicates, 86 studies were screened by title and abstract, resulting in 74 full-text assessments. Following eligibility evaluation, 57 high-quality sources were retained for final synthesis.

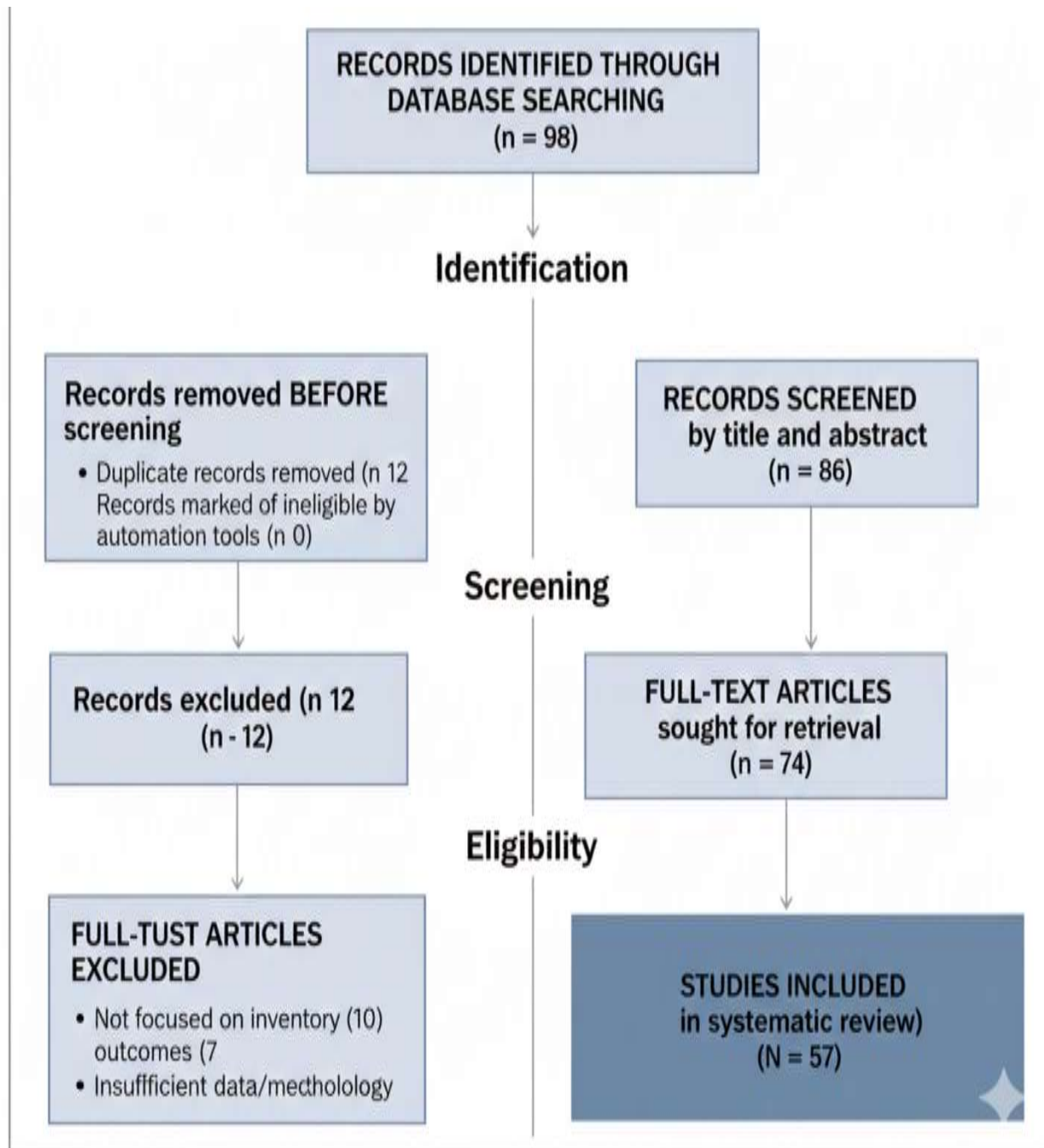


Figure 1: PRISMA Flow Diagram of Study Selection Process

Data Extraction and Analysis

A standardized extraction template was used to capture study characteristics, technological focus, implementation outcomes, and identified barriers. The extracted data were analyzed using thematic synthesis to identify recurring patterns relating to technological integration, operational benefits, and adoption constraints. Backward and forward citation tracking was additionally employed to improve coverage of influential studies omitted during the initial keyword search.

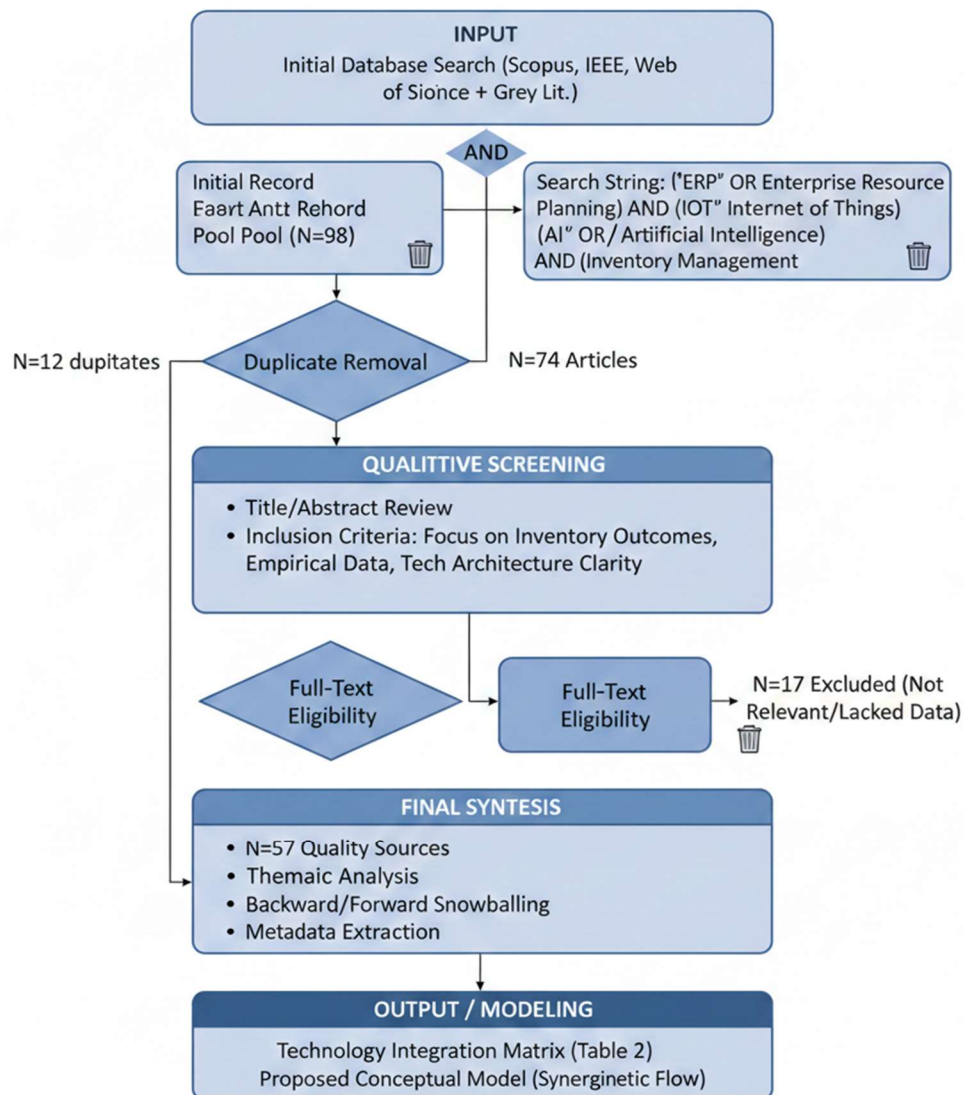


Figure 2: Methodological Roadmap of the SLR Process for Smart Inventory Management

Results of the Systematic Synthesis

The implementation of the PRISMA-based search plan provided a final list of 57 articles that passed the inclusion criteria in terms of technological focus and methodology rigor. The studies reflect a 10-year progression of inventory management across the world, encompassing not only the classic categorization approaches but also the futuristic cyber-physical ecosystems. Table 1 synthesizes the main nature, methodologies and gaps of these fundamental studies. This table provides the empirical background for further trend analysis and thematic discussion.

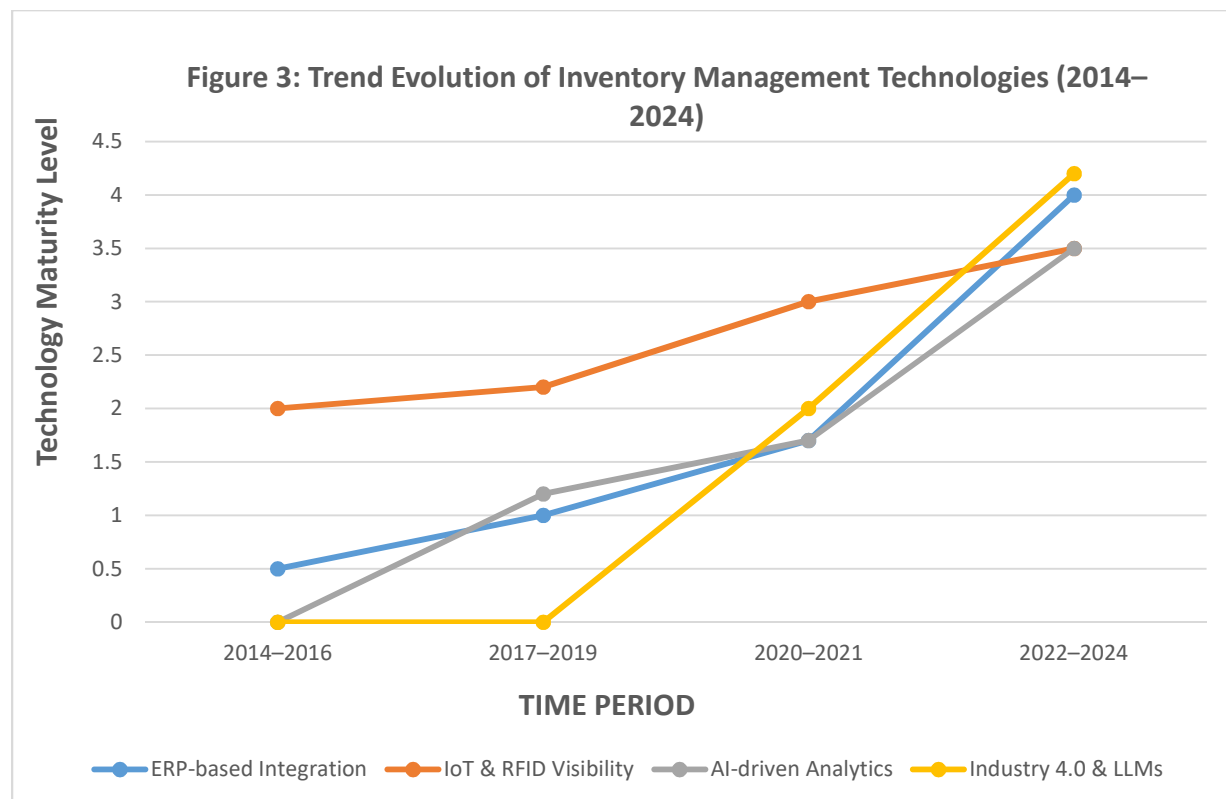
Table 1: Systematic Synthesis of Key Literature on Inventory Management Technologies

Author(s) & Year	Technology Focus	Methodology	Key Contributions	Research Gap
Pandya & Thakkar (2016)	ABC/XYZ Analysis	Literature Review	Confirmed the usefulness of traditional categorisation for cost prioritisation	Lack of real-time visibility and is outdated (before the implementation of Industry 4.0 digital technologies)
Acar et al. (2018)	ERP System	Case-Study Approach	ERP systems enable cross-functional coordination in the new markets	The study did not pay significant attention to real-time IoT integration or predictive analytics
Manavalan & Jayakrishna (2019)	IoT & Industrial 4.0	PRISMA Systematic Review	Suggested an IoT-driven sustainable supply-chain visibility framework	The article has a manufacturing-centric approach and provides minimal coverage of artificial intelligence or synergies of large-language models
Tan & Sidhu (2022)	RFID-IoT Integration	SLR	Confirmed RFID-IoT integration in automated sensing and interoperability in supply-chain management	The paper did not highlight its particular cybersecurity concerns and cost barriers in organisations
Alshahrani (2023)	Industry 4.0 Maturity	PRISMA Systematic Review	Identified the benefits of efficiency and sustainability of Industry 4.0 maturity in new markets	Literature is limited on the topic of synergistic technology adoption in small-and medium-sized enterprises
Fang et al. (2024)	Digital Transformation	Empirical Synthesis	Linked the adoption of digital tools to increase demand-predictive feasibility	The article does not respond to the practical barriers of implementation in firms with limited resources.
Teixeira et al. (2025)	Artificial Intelligence (AI)	Systematic Literature Review	Verified the effectiveness of artificial intelligence in predicting demand and improving warehouse optimisation	The inclusion of artificial intelligence with legacy ERP systems is still in its infancy
Chowdhury (2025)	Large Language Model	Conceptual Framework	Investigate the application of large-language models in automated knowledge extraction and decision support	The study has not been validated empirically and has not been experimented with live IoT streams
Paul et al. (2025)	Smart Inventory System	Case-Based Study Model	Developed an IoT-based system to provide automated replenishment notices	It lacks longitudinal success records in the developing economies
Zhang et al. (2025)	RFID & Socio-Technical	Systematic Review	Reveals the importance of the organisational culture in the adoption of technology	Additional research is required regarding the support of the policy and the cost-benefit analysis on a large scale

As shown in Table 1, studies published after 2020 increasingly shifted from isolated IoT applications toward integrated AI-driven inventory systems (Fang et al., 2024; Teixeira et al., 2025; Jaiswal, 2025). At the same time, several studies identified persistent adoption barriers among SMEs in emerging economies, including infrastructure limitations, implementation costs, and skills shortages (Alshahrani, 2023; Kumar & Singh, 2024; Haider & Lucas, 2024).

Trend Evolution Analysis

The longitudinal review of the 57 selected studies demonstrates that there is a clear technological migration between 2014 and 2024. This development is marked by the process of transformation of the old, non-evolutionary systems of records to the new increasingly automated and data-driven systems. This trajectory as visualised in Figure 3, can be divided into four evolutionary milestone.



The timeline shows how the emphasis has changed between Foundational Integration (Phase 1), where the reliance was on ERP to address internal data silos, and the current state of AI-enabled inventory decision systems (Phase 4). In the middle stages, the growth of IoT gave the Sensory Layer that was needed to have real-time visibility, which in turn triggered the creation of AI-based predictive models.

The reviewed literature suggests increasing reliance on AI-assisted inventory decision systems, particularly in predictive forecasting and warehouse optimisation (Teixeira et al., 2025; Tubis & Rohman, 2023). However, empirical evidence on the operational deployment of LLMs and Digital Twins remains limited, with most studies discussing their future potential rather than large-scale implementation (Choi & Lambert, 2022; Chowdhury, 2025).

Thematic Discussion

The Integration Synergies and Digital Divide

Although the trend analysis (Section 4.2) determined the chronological order, this thematic discussion questions the processes and motives behind the influence of Industry 4.0 on inventory management. Through the synthesis of 57 core studies, two major themes can be identified, including the need to stack technologies and the socio-economic limitations that characterise emerging markets.

Synergistic Integration: Records to Reasoning (RQ4)

The reviewed studies suggest that the effectiveness of smart inventory management depends on interoperability among ERP, IoT, AI, and RFID technologies rather than isolated implementation. As seen in Table 2, several studies emphasise that the effectiveness of Industry 4.0 inventory systems depends on interoperability among ERP, IoT, RFID, and AI technologies rather than isolated implementation (Pontoh et al., 2024; Tan & Sidhu, 2022; Teixeira et al., 2025). ERP systems provide integrated data infrastructure, IoT and RFID improve real-time visibility, while AI enhances forecasting and decision support capabilities.

Studies on AI-enabled inventory systems report improvements in predictive analytics, anomaly detection, and automated replenishment decisions (Teixeira et al., 2025; Bouchrika & Elhajj, 2023). However, the literature also indicates that these benefits depend heavily on data quality, interoperability, and technical expertise. From the RBV perspective, the integration of these technologies may contribute to the development of organisational dynamic capabilities that improve responsiveness and operational resilience.

The Paradox of Emerging Markets (RQ3) and the SME Barrier

One of the key findings of this systematic literature review is the increasing Digital Divide in some areas, such as Nigeria. Regardless of these theoretical benefits, studies focusing on emerging economies consistently report that SMEs could benefit substantially from digital inventory technologies, yet adoption remains constrained by infrastructure deficits, implementation costs, and limited digital capabilities (Alshahrani, 2023; Mefid & Ridhaningsih, 2024; Kumar & Singh, 2024).

The study outlines the presence of a three-level obstacle to transformation:

- i. **Systemic Infrastructure Failures:** Phase 4 (Cognitive Ecosystems) is a high-end technology requiring everywhere connectivity and power. Research on emerging-market supply chains suggests that unreliable electricity supply, unstable internet connectivity, and high implementation costs significantly limit SME adoption of IoT-enabled inventory systems in countries such as Nigeria (Alshahrani, 2023; Awoyemi & Awoyemi, 2025).
- ii. **The Cognitive Labour Gap:** Moving to the “Human-on-the-loop” surveillance requires expert data literacy. The literature reports a sharp lack of human resources that can understand the AI-based demand cues, so they have to resort to a kind of Technological Rejection, i.e. the discarding of costly systems in favour of manual overrides.
- iii. **The Capital-Resilience Trade-off:** The high ROI uncertainty of AI and Digital twins, as mentioned in the “Main Challenges” column of Table 2, makes it a risky sunk cost for SMEs with small liquidity. Therefore, to apply to the case of Nigerian businesses, modular, low-cost adoption, i.e. using open-source AI and open-source ERP alongside legacy ERP, is a more feasible route than complete automation.

Table 2: Multi-Layered Technology Integration Matrix

Technology	Strategic Synergies & Benefits	Primary Implementation Barriers	Identified Research Gaps
ERP.	Centralised data structure allows the integration of various sources of information, thus supporting the operation of cross-functional teams and improving the predictability.	These systems are costly to implement, create organisational resistance and face incompatibilities with legacy platforms	More frameworks that could facilitate the use of the Internet of Things, artificial intelligence, and blockchain technologies in the context of small-to-medium enterprises are still lacking.
IoT.	End-to-end visibility in supply-chain networks is increased by real-time telemetry, which is supported by automated replenishment alerts	This solution puts organisations at risk of cybersecurity attacks, requires major investment in infrastructure, and poses the challenge of interoperability of protocols	The empirical validation of such technologies is limited in the developing economies, and the available researches indicate the type of fragmentation in the integration of ERP and artificial intelligence systems
RFID	RFID identification eliminates manual error and provides high precision without error in its stock	The technology is, however, derailed by the large unit costs of tags and readers, difficulty in handling large amounts of data, as well as a lack of international standardisation	The longitudinal studies of the cross-industrial synergistic preparedness of RFID and IoT applications are scarce
AI	The basis of the modern artificial-intelligence solutions is advanced demand forecasting, prescriptive analytics, and intelligent inventory optimization	It requires stringent data validity, runs extensive computational expenses, and faces a severe lack of specialised technical expertise	This leaves the study on how to integrate legacy ERP systems with the establishment of viable deployment systems in small-to-medium enterprises in its early stages
Blockchain.	Unalterable audit logs, decentralised disclosure, and improved provenance offer a strong platform of supply-chain traceability.	The complexity of the architectures of blockchain systems, the issues of scalability, and the hardness of interoperability with the already existing data silos are a big challenge.	The application of blockchain to IoT and ERP in emerging-market supply chains has not been fully studied
Digital Twin	Dynamic decision making is facilitated by high-fidelity real-time simulation, together with predictive control loops	The prohibitive setup cost, excessive system complexity and strong reliance on high-quality real-time data constrain the wide adoption	The empirical data covering the cost-efficiency of a digital twin solution for small-scale businesses is currently lacking.
LLMs	Big language models provide cognitive assistance, automatic intelligent reporting, and synthesising unstructured information	The significant investments in training, limitations due to data privacy laws, and inability to guarantee domain-specific interpretability destroy their application	At this point, there is very little research on real-time application of large-language models to IoT, ERP, and RFID sensory streams.

Proposed Conceptual Model

Thematic synthesis of the published literature and recognition of technological synergies led to the development of the Integrated Smart Inventory Management Conceptual Model (Figure 4). The model is a strategic plan that supports the transformation of the siloed data management to a cohesive, cognitive inventory architecture.

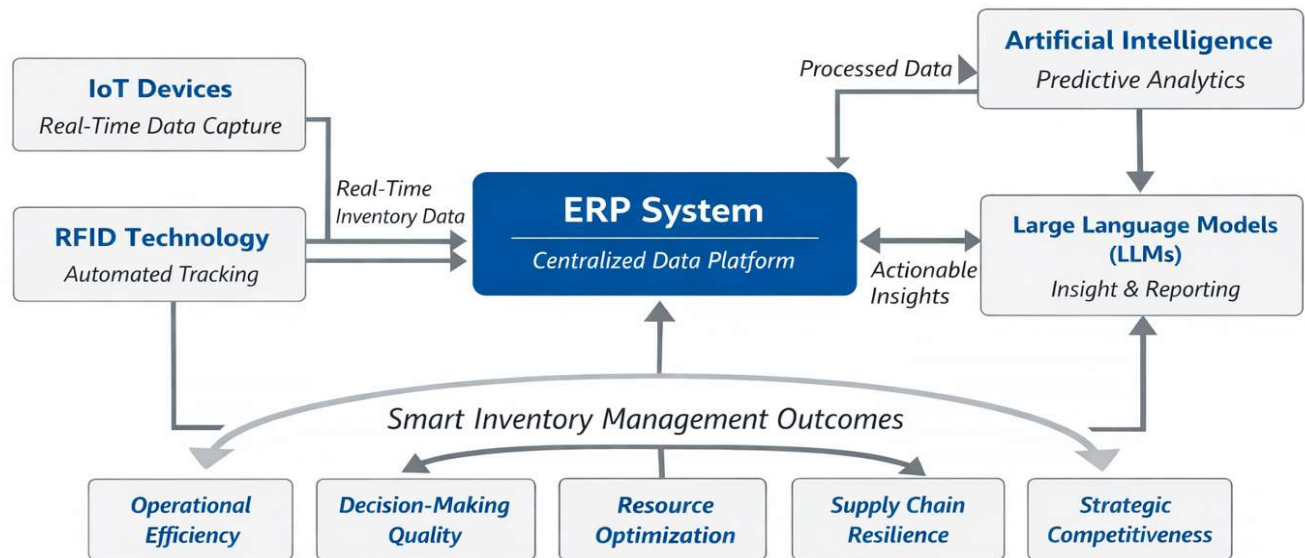


Figure 4: The Integrated Smart Inventory Ecosystem

Model Components and Functional Logic

The structure of the framework, as depicted in Figure 4, has four major technological pillars that support a smooth data to decision-based pipeline.

Data Acquisition Layer (IoT & RFID) serves as the sensory connection of the warehouse, which allows capturing high-fidelity, real-time data and automated tracking to eliminate human error and manual latency. The Centralised Core (ERP System) is the nervous system or the centralised data platform; the ERP integrates the different streams of data into a single source of truth, and organisational alignment is achieved. The Analytical Intelligence (AI & LLMs) layer denotes the cognitive engine, whereby the data held by the ERP gets fed into the AI models to perform predictive analytics. Large Language Models (LLMs) are introduced to produce actionable insights, which convert complex outputs of an algorithm into natural language reports to cross-functional stakeholders.

Strategic Outcomes and Theoretical Alignment

The model is based on five key outcomes intended to fill the empirical gaps identified in Table 1. Several reviewed studies associate integrated ERP-IoT-AI systems with improved inventory visibility, forecasting accuracy, and operational responsiveness (Fang et al., 2024; Jaiswal, 2025; Teixeira et al., 2025). These findings suggest that technological integration may strengthen supply-chain resilience and operational competitiveness. Resource-Based View (RBV) is operationalised through the architecture, which transforms the heterogeneous technological assets into an integrated, imitable organisational capability that can be maintained as a source of competitive advantage.

Practical Implications for Industry

The Integrated Smart Inventory Ecosystem (ISIE) is a holistic strategic plan of action that can be used by the managers of warehouses and supply-chain leaders facing the complexities of digital transformation. The foundation of this framework is a modular implementation strategy, which is especially relevant to enterprises located in emerging markets like Nigeria. As an alternative to capital-intensive, wholesale automation, managers are encouraged to adopt a gradual integration process, placing the stabilization of the ERP core in the first place before increasing the hardware, such as the Internet of Things and RFID sensors. This incremental process has the benefit that the data architecture is robust enough to receive the next wave of real-time sensory data.

Moreover, the integration of LLMs, as presented in the ISIE model, refashions the working position of the inventory manager. The move of the manual data entry system to a human-in-the-loop data management approach allows the staff to change their clerical duties to strategic interpretation. By using LLMs to convert the outputs of complex algorithms into insights using natural language, managers can make decisions based on coherent reports, instead of having to argue with the raw and unstructured spreadsheet.

Lastly, Empirical studies reviewed in this paper indicate that AI-enabled forecasting systems can reduce inventory inefficiencies and improve warehouse optimization, with some studies reporting inventory cost reductions of up to 20% (Teixeira et al., 2025; Jaiswal, 2025).

Conclusion

This study systematically reviewed the evolution of inventory management technologies between 2014 and 2024, with particular attention to the integration of ERP, IoT, RFID, AI, and Large Language Models (LLMs) within Industry 4.0 environments. The findings indicate a gradual transition from traditional ERP-centred systems toward more integrated and data-driven inventory management approaches that combine real-time visibility, predictive analytics, and automated decision support.

The review further demonstrates that the benefits of smart inventory management are increasingly linked to technological interoperability rather than the isolated adoption of individual tools. Across the reviewed studies, integrated systems were associated with improved inventory visibility, forecasting accuracy, operational responsiveness, and supply-chain resilience. However, the findings also reveal persistent implementation barriers, especially among SMEs and organizations in emerging economies, where infrastructure limitations, high implementation costs, and shortages of digital skills continue to constrain adoption.

Based on the thematic synthesis, the study proposed the Integrated Smart Inventory Ecosystem (ISIE) framework as a conceptual model for understanding the layered interaction between ERP systems, IoT-enabled visibility, and AI-driven analytics. Rather than presenting the framework as a universally validated solution, the study positions it as a structured roadmap that may guide future research and phased digital transformation efforts in resource-constrained contexts.

Finally, the review highlights that the future of inventory management will likely depend on the effective integration of complementary digital technologies and the ability of organizations to align technological investment with operational capability, workforce readiness, and infrastructural realities.

Limitations and Future Research

Despite the comprehensive nature of this systematic literature review, several limitations should be acknowledged. First, the study is based primarily on secondary evidence drawn from peer-reviewed publications and selected industry reports; therefore, the findings depend on the quality and scope of the available literature. Although the inclusion of industry reports improved coverage of recent Industry 4.0 developments, such sources may vary in methodological transparency compared with academic studies.

Second, the proposed Integrated Smart Inventory Ecosystem (ISIE) framework remains conceptual and has not yet been empirically tested in specific industrial or organizational settings. Future studies should therefore examine the practical applicability of the framework through case studies, surveys, or longitudinal investigations across different sectors and regions.

In addition, while the review identified major barriers affecting SMEs and emerging economies, further empirical research is needed to evaluate the cost-effectiveness, scalability, and operational outcomes of phased digital adoption strategies. Future research may also explore cybersecurity risks, data governance, and ethical concerns associated with AI- and LLM-enabled inventory systems as these technologies continue to evolve.

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