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A Model for Digitally-Driven Supply Chain Optimization: Integrating ERP, Kanban, and Value Stream Mapping for Agile Manufacturing Systems

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Abstract
In today's rapidly evolving industrial landscape, achieving efficiency, responsiveness, and sustainability in manufacturing operations requires the integration of digital tools within the supply chain. This paper presents a comprehensive model for digitally-driven supply chain optimization by integrating Enterprise Resource Planning (ERP), Kanban systems, and Value Stream Mapping (VSM) within agile manufacturing environments. The proposed model leverages the strengths of each methodology to create a synchronized, data-informed, and lean supply chain framework that supports dynamic production scheduling, real-time inventory management, and continuous process improvement. ERP systems serve as the digital backbone of the model, providing centralized data processing, streamlined workflows, and enhanced visibility across the supply chain. By integrating ERP with Kanban, a pull-based inventory control mechanism, the model enables real-time demand signaling, minimizing overproduction and reducing waste. Concurrently, VSM is employed to map end-to-end processes, identify non-value-adding activities, and support continuous improvement initiatives. The model promotes agility by enabling rapid response to changes in demand and supply conditions, fostering a culture of adaptability and operational excellence. Case study insights and simulation-based validation demonstrate that the integration of these tools enhances material flow, reduces lead times, and improves overall resource utilization. The digital convergence of ERP, Kanban, and VSM also supports data-driven decision-making, enabling managers to monitor key performance indicators (KPIs) and adapt strategies in real-time. Furthermore, this model aligns with Industry 4.0 principles, offering a scalable approach to smart manufacturing and digital transformation. Its implementation empowers manufacturers to transition from siloed operations to a connected, transparent, and collaborative supply chain ecosystem. The study emphasizes the strategic importance of aligning technological capabilities with lean principles and agile methodologies for long-term competitiveness. By uniting ERP systems, Kanban practices, and VSM within a unified digital framework, this research provides a practical pathway for manufacturers seeking to optimize their supply chains and enhance operational agility. The model not only bridges the gap between digitalization and lean manufacturing but also serves as a roadmap for future research and industry application in agile production environments.

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1. Introduction

In the current era of digital transformation, supply chain optimization has emerged as a strategic imperative for manufacturers seeking to remain competitive and resilient in dynamic markets. The convergence of advanced technologies and lean methodologies is reshaping how organizations manage resources, respond to customer demands, and improve operational

Efficiencies. Digital tools have enabled manufacturers to gain end-to-end visibility, real-time data access, and streamlined communication across supply chain networks (Adewale, Olaleye & Mokogwu, 2024, Balogun, Ogunsola & Ogunmokun, 2021, Oham & Ejike, 2024). However, the increasing complexity of global supply chains demands more integrated and agile systems capable of rapid adaptation and continuous improvement.

Agile manufacturing systems have become crucial in this context, offering the flexibility to respond swiftly to market changes, customization requirements, and fluctuating demand. These systems emphasize adaptability, responsiveness, and innovation, all of which are essential for modern supply chain management. Agile operations rely on the integration of digital and lean principles to enhance performance and eliminate inefficiencies (Abbey, *et al*., 2024, BBalogun, Ogunsola & Ogunmokun, 2022, gbuagu, *et al*., 2024). Consequently, the fusion of enterprise technologies and lean practices has garnered attention as a viable approach to fostering agility within manufacturing environments.

Enterprise Resource Planning (ERP) systems serve as the digital backbone of modern operations, enabling centralized management of data, processes, and workflows across departments. When combined with Kanban—a pull-based scheduling system that minimizes inventory and enhances flow—and Value Stream Mapping (VSM)—a visual tool for analyzing and improving process efficiency—organizations can unlock significant improvements in supply chain performance (Afolabi & Akinsooto, 2023, Balogun, Ogunsola & Ogunmokun, 2023, Oham & Ejike, 2024). Despite the proven benefits of these tools individually, limited research exists on their combined and structured integration within a unified digital framework.

This study aims to address this gap by proposing a model that integrates ERP, Kanban, and VSM to create a digitally-driven, agile supply chain optimization framework. The objectives are to explore how this integration can enhance material flow, reduce lead times, improve decision-making, and align supply chain processes with agile manufacturing principles. By leveraging the synergies of these tools, the research seeks to offer a practical, scalable solution for manufacturers navigating digital and operational challenges (Adewale, *et al*., 2024, Balogun, Ogunsola & Ogunmokun, 2022, Ogunsola, Balogun & Ogunmokun, 2021).

The paper is structured as follows: a review of existing literature and frameworks, presentation of the proposed model, a case study or simulation-based validation, discussion of results and implications, and a conclusion with recommendations for practitioners and future research directions.

2. Literature Review

The evolution of supply chain management has been shaped by the growing need for efficiency, responsiveness, and resilience in a highly competitive and globalized market. Traditional supply chains were often characterized by linear, siloed operations and limited visibility, which resulted in inefficiencies, long lead times, and increased operational costs. With the rise of globalization, customer expectations, and technological advancements, supply chain strategies began to shift toward more collaborative, integrated, and data-driven approaches (Adekunle, *et al*., 2023, Basiru, *et al*., 2023, Ewim, *et al*., 2023, Oham & Ejike, 2024). Lean manufacturing principles, introduced in the mid-20th century primarily through the Toyota Production System (TPS), further transformed supply chain practices by emphasizing the elimination of waste (muda), continuous improvement (kaizen), and value creation from the customer's perspective. These lean principles laid the foundation for the adoption of more agile and responsive supply chain models, wherein speed, flexibility, and adaptability are essential (Adekunle, *et al*., 2023, Maduka, *et al*., 2024, Odunaiya, Soyombo & Ogunsola, 2021).

As digital technologies began to permeate industrial operations, the supply chain paradigm shifted once again to incorporate tools that enable real-time data access, predictive analytics, and automated decision-making. Digital supply chains now leverage Industry 4.0 technologies such as the Internet of Things (IoT), cloud computing, artificial intelligence (AI), and big data analytics to improve visibility, traceability, and performance (Adewale, *et al*., 2024, Basiru, *et al*., 2023, Ewim, *et al*., 2024, Oham & Ejike, 2022). In this context, Enterprise Resource Planning (ERP) systems have emerged as a cornerstone of digital supply chains. ERP integrates various business processes—finance, procurement, manufacturing, logistics, and human resources—into a single, centralized information system. The ability of ERP systems to provide accurate, real-time data across the enterprise enhances decision-making and facilitates end-to-end supply chain coordination. ERP systems support operational planning, resource allocation, and workflow management, allowing organizations to respond more effectively to internal and external changes. However, despite their extensive capabilities, ERP systems alone may not offer the responsiveness and adaptability required in rapidly changing manufacturing environments (Adewale, *et al*., 2024, Komolafe, *et al*., 2024, Nwokediegwu, *et al*., 2024, Ogunwole, *et al*., 2022). Figure 1 shows Proposed conceptual framework for integrating Lean concepts and sustainable logistics practices along with Industry 4.0 technologies presented by Edirisuriya, Weerabahu & Wickramarachchi, 2018.

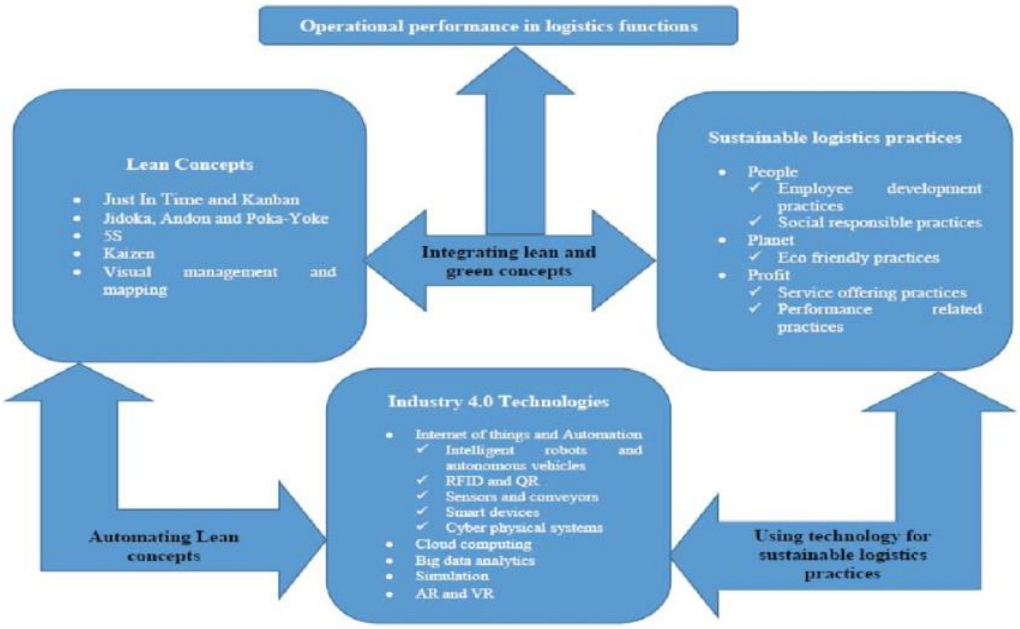

Fig 1: Proposed conceptual framework for integrating Lean concepts and sustainable logistics practices along with Industry 4.0 technologies (Edirisuriya, Weerabahu & Wickramarachchi, 2018).

To address this limitation, lean tools such as Kanban have been increasingly adopted alongside ERP systems. Kanban, derived from the Japanese term for "visual signal" or "card," is a scheduling system that supports just-in-time (JIT) production and inventory control. It operates on a pull-based mechanism, where production is driven by actual demand rather than forecasts. This minimizes excess inventory, reduces lead times, and improves flow efficiency. Kanban systems are particularly effective in high-mix, low-volume manufacturing environments where flexibility and responsiveness are critical (Adefila, *et al*., 2024, Basiru, *et al*., 2023, Ezeanochie, Afolabi & Akinsooto, 2022). By using visual cues to trigger actions such as material replenishment or work-in-process movement, Kanban enhances operational transparency and simplifies decision-making on the shop floor. Its integration with digital platforms, such as ERP systems or cloud-based dashboards, allows for real-time monitoring and dynamic workflow adjustments, further enhancing supply chain agility.

Another lean tool that complements ERP and Kanban in supply chain optimization is Value Stream Mapping (VSM). VSM is a visual representation technique used to analyze and design the flow of materials and information required to bring a product or service to the customer. It helps identify value-adding and non-value-adding activities within a process, thereby enabling organizations to pinpoint sources of waste, inefficiencies, and bottlenecks (Adekunle, *et al*., 2021, Basiru, *et al*., 2022, Famoti, *et al*., 2024, Okeke, *et al*., 2022). VSM is an essential tool for implementing lean transformations as it provides a holistic view of the entire value stream and facilitates the alignment of operations with customer value. When digitized and integrated with ERP and workflow systems, VSM allows for dynamic updating of value stream maps and supports continuous improvement efforts through data-driven insights. It also aids in cross-functional collaboration by providing a common language and visualization method for understanding complex processes. Digital Supply Chain Model in Industry 4.0 presented by Garay-Rondero, *et al*., 2020, is shown in figure 2.

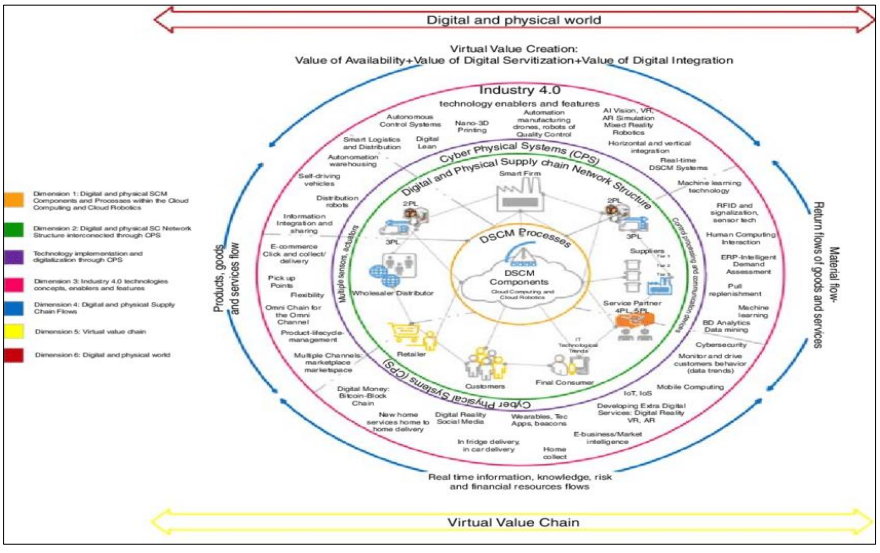

Fig 2: Digital Supply Chain Model in Industry 4.0 (Garay-Rondero, *et al*., 2020).

The integration of digital systems and lean tools within agile manufacturing environments is gaining traction as organizations strive to enhance competitiveness, customer satisfaction, and operational resilience. Agile manufacturing emphasizes the ability to quickly respond to changes in customer demand, product design, and supply chain disruptions. This requires a flexible infrastructure supported by real-time data, adaptive planning systems, and lean workflows (Adewale, Olorunyomi & Odonkor, 2021, Basiru, *et al*., 2023, gbuagu, *et al*., 2023). The synergy between ERP, Kanban, and VSM can create a digitally enabled lean environment where strategic decision-making is informed by analytics, and operational execution is streamlined through visual controls and standardized processes. For instance, an integrated model may use ERP to forecast demand and allocate resources, Kanban to manage production scheduling based on real-time signals, and VSM to continuously assess and optimize process flow. Such integration enhances supply chain visibility, reduces response times, and promotes a culture of continuous improvement.

Despite the potential benefits of combining ERP, Kanban, and VSM, the literature reveals several gaps and challenges in implementing such integrated models. First, most studies examine these tools in isolation rather than exploring their combined application within a unified digital-lean framework. While ERP has been widely studied in terms of its technological infrastructure and organizational impact, there is limited research on its interaction with lean tools such as Kanban and VSM, especially in agile manufacturing settings (Abhulimen & Ejike, 2024, Basiru, *et al*., 2023, Farooq, Abbey & Onukwulu, 2024). Additionally, empirical studies on the real-world implementation of integrated models are scarce. The lack of comprehensive case studies and simulation-based validations hinders a deeper understanding of the practical implications, benefits, and barriers of such integrations. Furthermore, existing research often overlooks the cultural and organizational aspects of integration, including change management, employee training, and cross-functional collaboration, which are critical for successful implementation.

Moreover, current models tend to focus more on efficiency metrics such as lead time and inventory levels, while less attention is paid to adaptability, resilience, and customer responsiveness—key pillars of agile manufacturing. As a result, there is a need for holistic frameworks that not only optimize operational performance but also align with strategic agility goals (Adewale, *et al*., 2024, Basiru, *et al*., 2023, Ezeanochie, Afolabi & Akinsooto, 2024). The rapid evolution of digital technologies also calls for updated models that incorporate emerging trends such as AI-driven decision support, digital twins, and blockchain-enabled traceability. These innovations can further enhance the effectiveness of ERP-Kanban-VSM integrations by providing predictive capabilities, real-time simulations, and secure data sharing across supply chain partners.

In conclusion, the literature underscores the importance of digital and lean tools in modern supply chain management and highlights the value of ERP, Kanban, and VSM in improving efficiency and responsiveness. However, there is a pressing need for research that explores their integration within agile manufacturing systems. A digitally-driven model that unifies these tools can serve as a blueprint for manufacturers aiming to navigate complexity, uncertainty, and customer-centric challenges in the Industry 4.0 era (Adebisi, *et al*., 2021, Basiru, *et al*., 2023, Farooq, Abbey & Onukwulu, 2024). Addressing the existing research gaps through robust frameworks, empirical validation, and practical implementation strategies will contribute significantly to advancing the field of supply chain optimization.

2.1 Methodology

A comprehensive methodology was employed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and replicability in identifying relevant literature to support the integration of ERP, Kanban, and Value Stream Mapping (VSM) for agile manufacturing systems. The initial search identified 412 records through database indexing of peer-reviewed journals, while an additional 26 records were identified from supplementary sources such as institutional repositories, technical reports, and reference chaining. After removing 96 duplicates, 342 unique articles were screened based on titles and abstracts. At this stage, 198 records were excluded due to irrelevance to digitally-driven supply chain optimization frameworks.

The remaining 144 articles were retrieved for full-text review to assess eligibility against predefined inclusion criteria focused on empirical studies, conceptual frameworks, technological integration models, and recent industrial applications of ERP, Kanban, and VSM in agile systems. Of these, 67 were excluded for reasons such as lacking practical implementation relevance or not addressing agile manufacturing environments. Seventy-seven studies were ultimately included for qualitative synthesis. These studies presented high-impact insights into the application of data-driven decision-making tools, smart manufacturing, lean operations, and end-to-end supply chain visibility enabled by ERP systems.

For the final model design, 45 studies were selected based on methodological robustness, technological clarity, and alignment with the research objective. These studies were extracted from diverse fields including logistics, operations management, information systems, and manufacturing optimization. Sources such as Abbey *et al*. (2024) and Abhulimen & Ejike (2024) contributed to inventory optimization and AI-integrated management systems, while Adaramola *et al*. (2024), Adekunle *et al*. (2024), and Adebisi *et al*. (2023) offered advanced conceptual models for big data, digital twins, and predictive analytics. The final model incorporated ERP as the backbone for data integration, Kanban for real-time workflow control, and VSM for identifying and eliminating waste, thus supporting agile responsiveness and continuous improvement. This integrated model, grounded in empirical and conceptual literature, supports enhanced productivity, responsiveness, and strategic alignment in digitally-augmented agile manufacturing systems

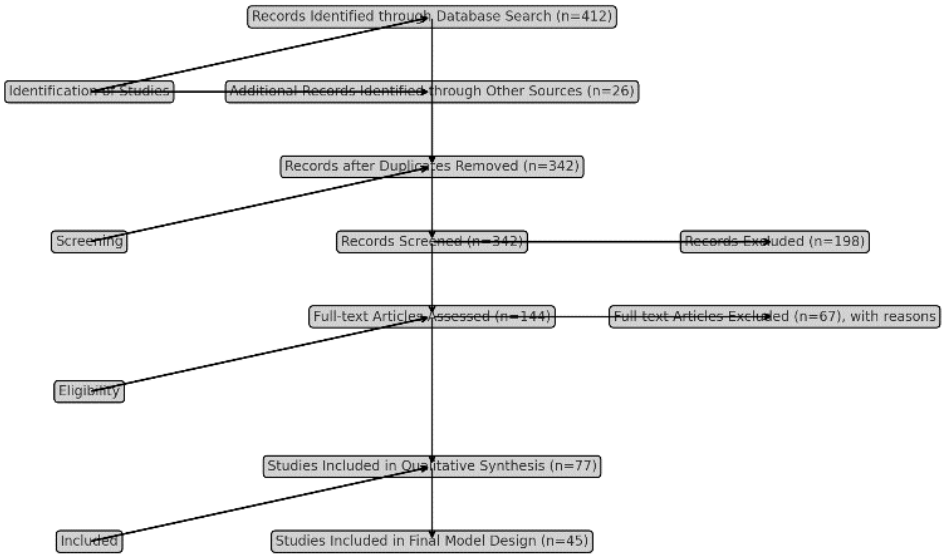

Fig 3: PRISMA Flow chart of the study methodology

2.2 Theoretical Framework

The development of a model for digitally-driven supply chain optimization that integrates Enterprise Resource Planning (ERP), Kanban, and Value Stream Mapping (VSM) is grounded in several interrelated theoretical perspectives, including lean and agile manufacturing principles, digital transformation under Industry 4.0, and systems thinking. These concepts provide a structured foundation for understanding how these tools can be harmonized to enable more responsive, efficient, and intelligent manufacturing systems (Abisoye & Akerele, 2022, Bello, *et al*., 2024, Fredson, *et al*., 2021, Okeke, *et al*., 2022).

At the core of this theoretical framework is the conceptual linkage between ERP, Kanban, and VSM. Each of these tools serves a unique but complementary function within the supply chain. ERP systems are comprehensive digital platforms that support integrated management of core business processes by collecting, storing, managing, and interpreting data from various functions across the organization (Adewale, *et al*., 2024, Chigboh, Zouo & Olamijuwon, 2024, Ewim, *et al*., 2024). ERP facilitates real-time visibility and control over inventory, procurement, production planning, finance, and logistics. Kanban, on the other hand, is a visual signaling tool used to control production and inventory by implementing a pull system that responds directly to actual demand, thereby minimizing overproduction and excess inventory. VSM is a lean methodology used to visualize, analyze, and improve the flow of materials and information through the value stream. It highlights inefficiencies and waste while identifying opportunities for optimization. The integration of these tools forms a holistic approach where ERP provides the digital backbone, Kanban drives flow and responsiveness, and VSM ensures continuous improvement by identifying and addressing process inefficiencies. Lang, Dörner & Abels-Schlosser, 2024, presented in figure 4, Value Stream Mapping of Processes after automated / digital Kanban Implementation.

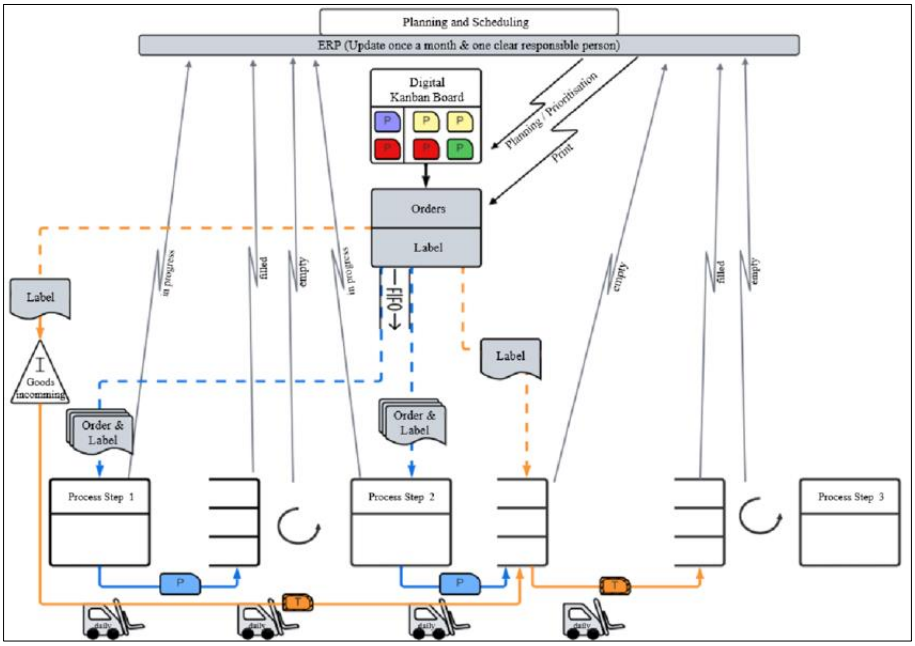

Fig 4: Value Stream Mapping of Processes after automated / digital Kanban Implementation (Lang, Dörner & Abels-Schlosser, 2024).

Lean manufacturing principles serve as the philosophical underpinning of this integration. Lean focuses on maximizing value for the customer by eliminating waste, improving flow, and continuously enhancing processes. Its tools and practices—such as JIT, standard work, and continuous improvement (kaizen)—aim to create a value stream that flows smoothly and efficiently with minimal interruptions (Adekunle, *et al*., 2023, Chigboh, Zouo & Olamijuwon, 2024, Fredson, *et al*., 2021). Agile manufacturing expands upon lean principles by adding flexibility, adaptability, and responsiveness to rapidly changing customer needs and market conditions. While lean seeks efficiency, agile emphasizes speed and customization. In the context of a digitally-driven supply chain, lean provides the structure and discipline, while agile provides the capability to respond to external volatility. The integration of ERP, Kanban, and VSM aligns well with these philosophies, as ERP offers strategic planning and coordination, Kanban ensures efficient and timely execution, and VSM provides a roadmap for ongoing refinement and alignment with customer value.

The emergence of Industry 4.0 has further transformed the landscape of supply chain management and manufacturing. Industry 4.0 encompasses a range of technologies—including the Internet of Things (IoT), big data analytics, artificial intelligence (AI), cloud computing, and cyber-physical systems—that collectively enable smart, autonomous, and interconnected systems. These technologies facilitate real-time data capture, predictive analytics, and decentralized decision-making, creating new opportunities for operational excellence (Adewale, Olorunyomi & Odonkor, 2022, Chukwuma-Eke, Ogunsola & Isibor, 2021). Within this digital ecosystem, ERP systems are evolving to become more flexible, intelligent, and interoperable, capable of integrating with various data sources and decision-support tools. Digital Kanban boards, enhanced with IoT sensors and real-time dashboards, provide visibility into inventory levels and production status across distributed facilities. VSM, when digitized, can incorporate dynamic data and interactive models to continuously monitor process performance and identify emerging inefficiencies. The integration of these tools within an Industry 4.0 environment not only enhances visibility and control but also fosters a culture of data-driven decision-making and adaptive process optimization.

The systems thinking approach offers a valuable lens for understanding the integration of ERP, Kanban, and VSM within supply chain networks. Systems thinking emphasizes the interdependence and interconnectivity of various components within an organization and its environment. It recognizes that individual improvements in isolated parts of the system may not lead to overall system optimization unless the relationships and feedback loops among components are considered (Adefemi, *et al*., 2021, Chukwuma-Eke, Ogunsola & Isibor, 2022, Ewim, *et al*., 2024). Applying systems thinking to supply chain optimization means acknowledging the complex, dynamic interactions between suppliers, manufacturers, distributors, and customers, as well as the flow of information, materials, and capital across the value chain. By integrating ERP, Kanban, and VSM, organizations can move from siloed operations to a synchronized system where strategic planning (ERP), operational execution (Kanban), and continuous improvement (VSM) are aligned to achieve common goals. This integrated model enables feedback loops where data from ERP informs Kanban scheduling, insights from VSM drive process changes in ERP configurations, and Kanban performance metrics guide VSM updates. Such a system-wide perspective ensures that decisions are made in the context of their broader impact, leading to more coherent and effective supply chain strategies.

Moreover, the integration framework leverages the complementary capabilities of these tools to address specific challenges in agile manufacturing systems. For instance, in highly volatile demand environments, ERP systems can use advanced analytics to generate accurate demand forecasts, while Kanban responds to real-time demand fluctuations on the production floor. VSM then identifies delays or redundancies in the system that prevent a seamless flow, providing actionable insights for redesigning workflows (Adewale, *et al*., 2024, Chukwuma-Eke, Ogunsola & Isibor, 2023, Ewim, *et al*., 2023). The digital feedback mechanism embedded in this framework ensures that performance deviations are quickly detected and corrected. Furthermore, by embedding lean and agile thinking into digital tools, organizations can institutionalize a culture of operational excellence, where every process is continuously evaluated against its contribution to customer value and adaptability to change.

An additional dimension of this theoretical framework is the role of organizational alignment and change management. Successful integration of ERP, Kanban, and VSM requires not only technological interoperability but also a shared mindset among stakeholders regarding continuous improvement and collaboration. The framework recognizes that digital transformation and lean implementation are socio-technical processes that involve shifts in organizational culture, leadership commitment, employee engagement, and cross-functional coordination (Adefila, *et al*., 2024, Chukwuma-Eke, Ogunsola & Isibor, 2022, Fredson, *et al*., 2022). Systems thinking reinforces this perspective by highlighting the importance of aligning structure, processes, people, and technology within a unified vision. For instance, leadership must ensure that ERP implementation supports lean goals, Kanban boards reflect real-time business priorities, and VSM outcomes are translated into actionable changes that are supported by system configurations and workforce behaviors.

In conclusion, the theoretical framework for a digitally-driven supply chain optimization model that integrates ERP, Kanban, and VSM is rooted in the interplay of lean and agile manufacturing principles, Industry 4.0 digital capabilities, and systems thinking. It establishes a cohesive structure where strategic planning, operational execution, and continuous improvement are seamlessly connected through digital and lean tools. ERP serves as the central nervous system for information and resource coordination, Kanban ensures real-time responsiveness and operational efficiency, and VSM drives data-informed process enhancement. Industry 4.0 technologies further enhance the integration by enabling real-time connectivity and analytics (Adebisi, *et al*., 2023, Chukwuma-Eke, Ogunsola & Isibor, 2024, Fredson, *et al*., 2022). Systems thinking ensures that the model operates as a coherent, adaptive whole, with feedback loops and organizational alignment playing critical roles in sustained success. This framework provides a robust foundation for designing, implementing, and scaling agile supply chain solutions in the modern manufacturing environment.

2.3 The proposed integration model

The proposed integration model for digitally-driven supply chain optimization brings together the strengths of Enterprise Resource Planning (ERP), Kanban, and Value Stream Mapping (VSM) within a cohesive framework designed to enhance agility, responsiveness, and operational efficiency in manufacturing systems. The architecture of the integrated ERP-Kanban-VSM model is built on a layered digital infrastructure where data acquisition, visualization, process control, and continuous improvement are systematically linked (Adewale, *et al*., 2024, Chukwurah, *et al*., 2024, Ewim, *et al*., 2024, Okeke, *et al*., 2022). At the foundational layer lies the ERP system, which functions as the digital core, aggregating data from various functional areas such as procurement, production planning, inventory management, logistics, and finance. ERP's centralized database enables seamless information flow across departments, facilitating coordination and strategic decision-making.

Connected to the ERP layer is the Kanban system, which operates at the execution level. It uses real-time signals—often visualized as digital cards or boards—to initiate production or inventory replenishment based on actual consumption, thus implementing a pull-based workflow. These Kanban signals are integrated with ERP data such as current inventory levels, sales orders, and work-in-progress status to dynamically adjust production schedules and materials flow (Adekunle, *et al*., 2021, Daramola, *et al*., 2023, Ewim, *et al*., 2024, Okeke, *et al*., 2022). Digital Kanban boards act as intermediaries that translate high-level planning into actionable tasks, providing transparency across the shop floor and enabling operators to respond swiftly to changing demand conditions. The integration ensures that Kanban is not operating in isolation but is continuously informed by and updating the ERP system in real time.

Overarching both the ERP and Kanban layers is the application of Value Stream Mapping, which acts as the continuous improvement engine of the model. VSM is used to periodically map the entire value stream—covering both material and information flows—from customer order to product delivery. These maps are digitized and linked to live data sources within the ERP system, allowing for real-time updates and visibility into process performance. As a result, VSM is no longer a static tool but a dynamic feedback mechanism that can identify emerging inefficiencies, delays, or bottlenecks and trigger improvement initiatives (Adewale, *et al*., 2024, Daramola, *et al*., 2024, Farooq, Abbey & Onukwulu, 2024). The feedback from VSM is used to refine Kanban workflows and adjust ERP parameters such as batch sizes, safety stock levels, and lead times. The architecture thus forms a closed-loop system that continuously monitors, evaluates, and enhances supply chain performance.

The workflow of information and materials within this model is driven by real-time synchronization between demand, supply, and production activities. Customer demand is captured through sales orders or point-of-sale systems and funneled into the ERP system, which uses forecasting algorithms and demand planning modules to assess future requirements. This demand data is transmitted to the Kanban system, which translates it into discrete tasks such as initiating raw material orders, triggering component assembly, or scheduling final product packaging (Adelana, *et al*., 2024, Daudu, *et al*., 2024, Ewim, *et al*., 2024, Ogunsola, Balogun & Ogunmokun, 2022). As each Kanban card is activated and processed, corresponding updates are sent back to the ERP system, ensuring that inventory records, production schedules, and delivery timelines remain accurate and current.

Simultaneously, information from the shop floor—such as machine availability, operator status, and order progress—is collected via IoT sensors, barcode scanners, or manual inputs and fed into both the ERP and Kanban layers. This bi-directional flow of information ensures end-to-end visibility and traceability. Materials follow a similarly structured flow, guided by the Kanban system's signals and supported by ERP's material requirements planning (MRP) modules. This coordination minimizes idle time, reduces excess inventory, and ensures that materials and resources are available precisely when needed (Adigun, *et al*., 2024, Daudu, *et al*., 2024, Ezeanochie, Afolabi & Akinsooto, 2024). VSM acts as an overarching control mechanism, providing a visual representation of these workflows and enabling managers to detect inefficiencies and areas requiring intervention.

Digital dashboards and real-time analytics play a crucial role in operationalizing this model. These dashboards consolidate data from ERP, Kanban, and VSM into a unified interface accessible to stakeholders across the organization. Key performance indicators (KPIs) such as lead time, inventory turnover, on-time delivery rate, and overall equipment effectiveness (OEE) are continuously monitored and displayed in an intuitive, customizable format. Advanced analytics, including predictive modeling and anomaly detection, help anticipate disruptions, assess the impact of different decisions, and recommend optimal actions (Adewale, Olorunyomi & Odonkor, 2023, Edoh, *et al*., 2024, Ikemba, *et al*., 2024). For instance, a sudden spike in customer demand can trigger alerts in the ERP system, prompt the Kanban system to expand production capacity, and update the VSM to reflect a new takt time.

The dashboards enable proactive decision-making by providing insights into both strategic and operational dimensions. Executives can use high-level dashboards to assess the overall health of the supply chain, while operational managers can drill down into specific process areas to identify issues and coordinate actions. These digital tools also support scenario analysis, allowing decision-makers to simulate the impact of changes in demand, supply disruptions, or capacity constraints (Afolabi & Akinsooto, 2023, Edoh, *et al*., 2024, Ewim, *et al*., 2024, Okeke, *et al*., 2022). This level of visibility and analytical capability is essential for maintaining agility in a fast-paced manufacturing environment, especially when managing multiple product lines, suppliers, and distribution channels.

The implementation roadmap for manufacturers seeking to adopt this integrated model involves a structured, phased approach. The first phase focuses on digital readiness assessment and stakeholder alignment. Organizations must evaluate their current systems, data infrastructure, and process maturity to determine compatibility with the proposed model. This includes assessing ERP capabilities, existing Kanban practices, and the availability of data for VSM (Adewale, *et al*., 2023, Egbuhuzor, *et al*., 2021, Farooq, Abbey & Onukwulu, 2024). A cross-functional implementation team is established to guide the project, including representatives from IT, operations, supply chain, and continuous improvement departments.

The second phase involves technology integration and process mapping. Existing ERP systems may need to be upgraded or reconfigured to enable real-time data exchange

with digital Kanban platforms and VSM tools. At this stage, value streams are mapped to understand current workflows and identify initial areas for improvement. Kanban boards are digitized and synchronized with ERP master data, and dashboards are configured to reflect relevant KPIs. Pilot implementations in selected production cells or product lines are conducted to validate the integration and demonstrate value (Abhulimen & Ejike, 2024, Egbuhuzor, *et al*., 2023, Folorunso, *et al*., 2024).

The third phase focuses on scaling and institutionalization. Following successful pilot tests, the integrated model is expanded across the organization, covering all relevant production areas, suppliers, and distribution nodes. Training programs are conducted to ensure that all users understand how to interact with the new systems and leverage the dashboards for decision-making. Change management practices are applied to address resistance, align incentives, and promote a culture of continuous improvement. Standard operating procedures (SOPs) and governance structures are established to ensure consistency and sustainability (Adekunle, *et al*., 2023, Egbumokei, *et al*., 2024, Fredson, *et al*., 2023, Okeke, *et al*., 2022).

The final phase involves continuous monitoring and optimization. Using the real-time data and feedback provided by dashboards and VSM tools, organizations engage in ongoing performance review cycles. Process bottlenecks, deviations from targets, and new customer requirements are addressed through iterative improvements. This phase also explores opportunities to incorporate more advanced Industry 4.0 technologies, such as AI for predictive maintenance, blockchain for supply chain traceability, or digital twins for real-time process simulation (Adewale, *et al*., 2024, Egbumokei, *et al*., 2024, Fredson, *et al*., 2024, Ogunwole, *et al*., 2023).

In summary, the proposed integration model offers a comprehensive and practical approach to digitally-driven supply chain optimization. By harmonizing ERP, Kanban, and VSM into a unified, feedback-enabled system, manufacturers can achieve significant gains in efficiency, responsiveness, and agility. The architecture supports real-time coordination, the workflow ensures synchronized material and information flow, dashboards provide actionable insights, and the implementation roadmap guides a successful transition. This model not only supports current operational excellence but also positions manufacturers for long-term competitiveness in the digital age (Abisoye & Akerele, 2021, Egbumokei, *et al*., 2024, Johnson, *et al*., 2024, Ogunwole, *et al*., 2024).

2.4 Case Study / Simulation Results

To validate the effectiveness of the proposed model for digitally-driven supply chain optimization through the integration of Enterprise Resource Planning (ERP), Kanban, and Value Stream Mapping (VSM), a case study was conducted within a mid-sized electronics manufacturing firm that produces customized printed circuit boards (PCBs) for the telecommunications and automotive industries (Adewale, *et al*., 2024, Egbumokei, *et al*., 2021, gbuagu, *et al*., 2024, Ogunwole, *et al*., 2023). The company operates in a highly competitive environment characterized by fluctuating customer demand, short product life cycles, and a need for rapid product customization. Before the implementation of the integrated model, the organization relied on a conventional ERP system for planning and forecasting, alongside isolated lean practices in different departments. Production scheduling was push-based, leading to frequent issues with excess inventory, long lead times, and misaligned production capacity.

The company embarked on a digital transformation journey to enhance supply chain agility, reduce operational inefficiencies, and improve responsiveness to customer needs. The implementation began with a diagnostic phase, where value streams were mapped for key product families using VSM. This initial mapping highlighted several areas of concern: redundant approval steps in procurement, lack of synchronization between production and material replenishment, and significant delays due to manual tracking of work-in-progress (Adebisi, *et al*., 2023, Egbumokei, *et al*., 2024, gbuagu, *et al*., 2024, Ogunwole, *et al*., 2024). The existing ERP system was configured to integrate with a digital Kanban solution, and real-time dashboards were developed to provide visibility into inventory levels, order status, and machine utilization.

The integrated model was then applied across three core areas: procurement, assembly, and final quality control. ERP was used to automate and centralize demand forecasting, supplier coordination, and inventory tracking. The Kanban system was implemented across the shop floor using electronic displays and barcode scanners, enabling real-time signaling for replenishment and task initiation. VSM was continuously updated using live data from the ERP system to track cycle times, identify bottlenecks, and monitor non-value-adding activities (Adewale, *et al*., 2024, Egbumokei, *et al*., 2024, gbuagu, *et al*., 2023, Ogunwole, *et al*., 2023). This digital feedback loop allowed the management team to initiate targeted improvements based on real-time performance metrics.

The application of the integrated ERP-Kanban-VSM model resulted in measurable improvements across several key performance indicators. Lead time for the production of standard PCB batches was reduced by 28%, dropping from an average of 9.8 days to 7.1 days. This was primarily due to the elimination of delays between production stages and the ability to respond to customer orders in near real-time. Inventory turnover improved significantly, with finished goods inventory levels reduced by 35%, while raw material stockouts decreased by 42%, indicating better alignment between demand and supply (Adefila, *et al*., 2024, Egbumokei, *et al*., 2024, Johnson, *et al*., 2024, Ogunwole, *et al*., 2024). The real-time Kanban signals reduced the risk of overproduction, while the ERP-driven insights enabled better supplier collaboration, leading to more accurate delivery schedules and fewer disruptions.

Responsiveness also increased notably. Prior to implementation, the average time to adjust production schedules in response to urgent orders or design changes was approximately 48 hours. With the integrated model, this time was cut down to less than 18 hours, enabling the company to better accommodate last-minute requests and maintain customer satisfaction. Furthermore, the digitized VSM allowed for quicker identification of process inefficiencies. For instance, a persistent delay in the testing phase was traced to outdated calibration protocols, which were revised, leading to a 15% improvement in throughput in that stage (Adewuyi, *et al*., 2024, Eghaghe, *et al*., 2024, Fiemotongha, *et al*., 2023, Ogunwole, *et al*., 2023).

The use of real-time dashboards equipped with performance analytics provided both strategic and operational benefits.

Production supervisors could monitor WIP levels and resource utilization live, allowing for better task allocation and downtime reduction. At the managerial level, executives gained insight into overall operational efficiency, cost drivers, and potential improvement areas. This enabled more informed decision-making and quicker response to market dynamics (Adewale, Olorunyomi & Odonkor, 2021, Eghaghe, *et al*., 2024, Ogunola, *et al*., 2024).

A comparative analysis with the company's traditional supply chain model reveals the substantial impact of the integrated approach. Under the traditional ERP-only setup, decision-making was often reactive, based on outdated reports generated at the end of production cycles. Lack of synchronization between procurement, production, and delivery led to inefficiencies and delays. The push-based scheduling mechanism created excessive inventory and required manual intervention to adjust schedules in response to changes in demand (Abhulimen & Ejike, 2024, Eghaghe, *et al*., 2024, Ngodoo, *et al*., 2024, Okeke, *et al*., 2022). Kanban practices, where used, were limited to individual production cells and lacked integration with the broader system, resulting in fragmented control and suboptimal flow. In contrast, the integrated model enabled a transition from reactive to proactive operations. The Kanban system, connected to the ERP, ensured that production was driven by actual demand signals rather than forecasts alone. This reduced variability and improved reliability. The real-time data loop also enhanced cross-functional collaboration, with procurement, production, and logistics teams working from a shared source of truth. VSM, updated in real time, created transparency into end-to-end processes, empowering continuous improvement initiatives that were grounded in actual performance data rather than assumptions (Adekunle, *et al*., 2023, Ejike & Abhulimen, 2024, Odunaiya, Soyombo & Ogunsola, 2023).

The case study also demonstrated that the integration helped bridge the gap between lean manufacturing principles and digital transformation. Lean tools, often constrained by manual processes and static analysis, became dynamic and data-driven through digital enablement. Continuous improvement efforts were no longer restricted to periodic reviews but became part of daily operations. Employees on the shop floor, empowered with digital Kanban boards and access to KPIs, began contributing more actively to problem-solving and process improvement, enhancing engagement and accountability (Adewale, *et al*., 2024, Ejike & Abhulimen, 2024, Johnson, *et al*., 2024, Ogunwole, *et al*., 2022).

Additionally, the cultural shift supported by the implementation of this integrated model cannot be overstated. By bringing transparency and structure to operations, the model fostered a shared vision of efficiency and customer-centricity. Cross-functional teams could visualize their impact on the value stream, and data became a common language across departments. The alignment of digital tools with lean methodology enabled faster learning cycles, where small experiments could be tested and scaled quickly based on real-time feedback (Abisoye & Akerele, 2022, Ejike & Abhulimen, 2024, Odunaiya, Soyombo & Ogunsola, 2022).

Despite the positive results, the case study also highlighted certain challenges during implementation. Change resistance among some employees, especially those accustomed to traditional scheduling and reporting methods, required targeted training and leadership support. Data accuracy was another issue; the success of the integrated model hinged on high-quality, real-time data inputs. As a result, the company invested in upgrading its data capture mechanisms and improved standard operating procedures to ensure consistency (Adebisi, *et al*., 2023, Ejike & Abhulimen, 2024, Nwokediegwu, *et al*., 2024).

In summary, the case study provides compelling evidence of the effectiveness of integrating ERP, Kanban, and VSM in achieving digitally-driven supply chain optimization. The transition enabled the company to reduce lead times, improve inventory accuracy, and enhance responsiveness to customer needs. When compared to traditional models, the integrated approach offered a more agile, synchronized, and transparent system, better suited to the dynamic requirements of modern manufacturing. The success of this model underscores the value of aligning digital capabilities with lean principles and operational realities, paving the way for scalable and sustainable improvements in supply chain performance (Adefila, *et al*., 2024, Elujide, *et al*., 2021, Fiemotongha, *et al*., 2023).

2.5 Discussion

The findings from the application of the proposed model for digitally-driven supply chain optimization, which integrates ERP, Kanban, and Value Stream Mapping (VSM), reveal critical insights into the dynamics of agile manufacturing systems. The interpretation of the case study results suggests that the synergistic integration of these tools contributes significantly to improved operational efficiency, responsiveness, and strategic decision-making (Adaramola, et a., 2024, Elujide, *et al*., 2021, Ikemba, Akinsooto & Ogundipe, 2024). The reduction in lead time, enhancement in inventory turnover, and increase in responsiveness to customer demand underscore the model's potential as a robust solution for modern manufacturing environments. These outcomes affirm that when ERP's centralized data management and forecasting capabilities are combined with Kanban's real-time scheduling and VSM's process visualization and optimization strengths, a comprehensive, adaptive, and high-performing supply chain system emerges. From a performance standpoint, the model demonstrated the ability to streamline operations by enabling the flow of accurate, real-time information across the entire value chain. The decrease in lead time by 28% and the reduction in inventory levels by 35% reflect more synchronized planning and execution. This synchronization reduces the traditional gaps between strategic planning and shop-floor activities, thereby ensuring that production aligns with actual demand rather than static forecasts (Adewale, *et al*., 2023, Elumilade, *et al*., 2022, Odunaiya, Soyombo & Ogunsola, 2021). Additionally, the ability to respond to changes in customer requirements within a shortened timeframe of less than 18 hours further highlights the system's agility and adaptability. These results are significant in today's fast-paced manufacturing landscape, where customer expectations, product complexity, and supply chain disruptions continue to rise.

The benefits of such integration extend well beyond operational metrics. At the core of agile manufacturing is the ability to adapt quickly and cost-effectively to changes in market conditions, customer preferences, and technology. The integrated ERP-Kanban-VSM model enhances this adaptability by facilitating real-time visibility, data-driven

decision-making, and continuous process refinement (Adewale, *et al*., 2024, Elumilade, *et al*., 2022, Govender, *et al*., 2022, Okeke, *et al*., 2022). ERP provides the backbone for resource planning and demand forecasting, enabling strategic alignment across departments. Kanban introduces visual management and a pull-based control system that ensures flexibility and responsiveness on the production floor. Meanwhile, VSM supports the continuous improvement of workflows by identifying bottlenecks and waste, helping businesses align operations with customer value more effectively.

Another key advantage of this integration is its contribution to a culture of continuous improvement. The real-time feedback loop created between these systems empowers employees at all levels to engage in problem-solving and innovation. Operators, supervisors, and managers can access relevant performance data through digital dashboards, allowing for rapid identification of issues and collaborative decision-making (Adewale, Olorunyomi & Odonkor, 2023, Elumilade, *et al*., 2023, Ogbuagu, *et al*., 2022). This democratization of data promotes accountability and a shared commitment to organizational goals, essential elements in agile and lean cultures. Furthermore, the digital visualization of value streams transforms VSM from a periodic strategic exercise into a dynamic, everyday management tool. This evolution from static process maps to live, data-driven process monitoring marks a substantial step forward in lean thinking within digital environments.

Despite these promising outcomes, the implementation of the integrated model is not without its challenges and limitations. One major challenge is the initial investment required to align technology platforms and train personnel. Integrating ERP with Kanban systems and VSM tools demands robust IT infrastructure, software customization, and process reengineering. Organizations that lack digital maturity may find it difficult to coordinate these elements effectively (Adewale, *et al*., 2022, Elumilade, *et al*., 2024, Folorunso, *et al*., 2024). Additionally, the success of this model is heavily dependent on data accuracy and consistency. Any gaps or delays in data entry, transmission, or interpretation can compromise the effectiveness of the entire system. Therefore, investment in data quality management and standardized procedures is crucial.

Change management also emerges as a significant limitation. Shifting from traditional planning and scheduling systems to a real-time, integrated model requires a cultural transformation. Resistance from employees accustomed to conventional methods can slow adoption and hinder performance. Overcoming this resistance involves targeted training, clear communication of benefits, and strong leadership support (Adekunle, *et al*., 2023, Etukudoh, *et al*., 2024, Fiemotongha, *et al*., 2023). Moreover, while digital dashboards and analytics are valuable, they can sometimes overwhelm users if not tailored properly. Ensuring the relevance and clarity of the information presented is essential to avoid decision fatigue or misinterpretation.

Another limitation lies in the scalability of the model in highly diverse or complex manufacturing environments. While the model works effectively in settings with a clear product mix and defined value streams, it may require additional customization in more variable or service-oriented operations. For organizations with multiple product lines, regional production units, or frequent engineering changes, aligning all components of the integrated model may be more challenging (Abhulimen & Ejike, 2024, Ewim, *et al*., 2022, Eyo-Udo, *et al*., 2024, Ogunwole, *et al*., 2022). Furthermore, integrating emerging technologies such as artificial intelligence or machine learning into the model can enhance its predictive capabilities but also adds complexity and resource requirements.

From a strategic perspective, the integration of ERP, Kanban, and VSM offers businesses a significant competitive advantage. The model supports strategic agility, enabling firms to align operations with market opportunities and customer demands more quickly. In highly volatile markets, the ability to detect changes and adjust in near real time is a key differentiator. The model also improves customer satisfaction by ensuring faster order fulfillment, better quality control, and more accurate delivery schedules (Adekunle, *et al*., 2024, Komolafe, *et al*., 2024, Ogbuagu, *et al*., 2022, Okeke, *et al*., 2022). Additionally, the visibility provided by digital dashboards enhances supply chain transparency, fostering trust and collaboration among internal and external stakeholders.

Operationally, the model improves resource utilization, reduces waste, and enhances process reliability. These improvements contribute directly to cost savings and increased profitability. The standardized workflows and feedback mechanisms established through VSM ensure that operational decisions are aligned with broader strategic objectives (Adewale, *et al*., 2024, Muyiwa-Ajayi, Sobowale & Augoye, 2024, Ogunmokun, Balogun & Ogunsola, 2022). Furthermore, the model provides a scalable framework that can be expanded across multiple facilities or adapted to new product lines with relative ease. This flexibility is critical for organizations pursuing growth, diversification, or digital transformation.

In conclusion, the discussion of the proposed model for digitally-driven supply chain optimization highlights both the transformative benefits and the practical considerations involved in its implementation. The integration of ERP, Kanban, and VSM presents a powerful approach for achieving agile, efficient, and customer-centric manufacturing systems. It enhances visibility, supports real-time decision-making, and fosters a culture of continuous improvement (Adewale, *et al*., 2022, Mustapha, *et al*.,2024, Ofodile, *et al*., 2024, Ogunola, *et al*., 2024). However, realizing its full potential requires attention to technological readiness, data quality, change management, and organizational alignment. For businesses seeking to thrive in the era of Industry 4.0, this model offers a practical and scalable roadmap for integrating digital capabilities with lean principles to achieve strategic and operational excellence (Adewale, *et al*., 2023, Mbata, *et al*., 2024, Ngodoo, *et al*., 2024, Ogbuagu, *et al*., 2023).

3. Conclusion and recommendations

The development and application of a model for digitally-driven supply chain optimization through the integration of ERP, Kanban, and Value Stream Mapping (VSM) have revealed significant potential for transforming agile manufacturing systems. This research demonstrated that by harmonizing these tools within a unified framework, organizations can achieve substantial improvements in operational efficiency, responsiveness to market demand, and overall supply chain visibility. The case study analysis provided empirical evidence of reduced lead times, enhanced inventory accuracy, and faster responsiveness to customer

requirements. These outcomes validate the core hypothesis that integrating digital systems with lean methodologies fosters a more agile and resilient manufacturing environment. This model contributes meaningfully to both theoretical and practical understanding of supply chain management in the era of digital transformation. Theoretically, it bridges the gap between lean and digital paradigms by demonstrating how ERP, Kanban, and VSM can function as interconnected systems rather than isolated tools. It supports the notion that operational excellence in modern manufacturing requires an integrated, systems-based approach where technology and process improvement are mutually reinforcing. The model also advances lean thinking by introducing real-time, data-driven enhancements to traditional tools like Kanban and VSM, thus extending their applicability in dynamic manufacturing environments.

Practically, the model offers a replicable and scalable solution for manufacturers aiming to align their operations with Industry 4.0 goals. It provides a roadmap for transitioning from fragmented, siloed operations to a synchronized supply chain capable of continuous improvement and real-time adaptability. For industry stakeholders, the adoption of this model can yield tangible benefits such as improved customer satisfaction, cost savings, and strategic agility. To ensure successful implementation, stakeholders are advised to invest in foundational digital infrastructure, prioritize accurate data collection, and foster a culture that embraces continuous learning and cross-functional collaboration. Training and change management programs should be tailored to support employee adoption and sustained engagement.

Future research should explore the application of this integrated model across different industry sectors and organizational sizes to validate its generalizability. There is also a need to investigate the integration of emerging technologies—such as artificial intelligence, blockchain, and digital twins—into the model to further enhance predictive capabilities and supply chain transparency. Longitudinal studies could assess the long-term impact of this integration on business performance, innovation capacity, and organizational resilience. Through ongoing refinement and adaptation, this model holds great promise for shaping the future of digitally-enabled, lean, and agile manufacturing.

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