



Article

LEAN MANUFACTURING AND ERP INTEGRATION: A SYSTEMATIC REVIEW OF PROCESS EFFICIENCY TOOLS IN THE APPAREL SECTOR

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ABSTRACT

The apparel manufacturing sector faces mounting pressure to simultaneously enhance productivity, reduce operational waste, and maintain compliance with dynamic buyer standards in an increasingly globalized and time-sensitive market. This systematic review investigates the integration of Lean Manufacturing principles and Enterprise Resource Planning (ERP) systems as a dual strategy to improve process efficiency across apparel production environments. Lean Manufacturing—originating from the Toyota Production System—focuses on minimizing waste and non-value-adding activities using tools such as Just-in-Time (JIT), 5S, Value Stream Mapping (VSM), and continuous improvement (Kaizen). ERP systems, by contrast, provide real-time visibility and control over core organizational functions through centralized data management and modular functionality. While these systems have traditionally been deployed in parallel, emerging scholarship suggests their combined application offers synergistic benefits, especially within the apparel sector characterized by high SKU variability, labor intensity, and volatile demand cycles. This review synthesizes evidence from 96 peer-reviewed articles published between 2000 and 2023, following PRISMA guidelines to ensure methodological transparency. The selected studies span five major apparel manufacturing hubs—Bangladesh, India, Vietnam, Turkey, and China—accounting for over 65% of global apparel exports. The review categorizes findings into five thematic domains: lean-ERP integration models, implementation strategies, sector-specific challenges, performance outcomes, and critical success factors. Empirical evidence from 51 studies highlights significant improvements in lead time (20–45%), defect rate reduction (10–25%), and operational cost savings (15–30%) post-integration. Additionally, 34 case-based studies document enhanced traceability, floor-level standardization, and better buyer compliance documentation. The analysis reveals that integration success depends on context-specific variables including firm size, digital infrastructure, leadership commitment, and organizational culture. Implementation strategies such as phased rollouts and agile methods consistently outperform big-bang approaches due to their adaptability and capacity to embed feedback loops. However, barriers such as ERP complexity, limited lean literacy among IT teams, poor change management, and resistance from middle management continue to hinder outcomes, especially in resource-constrained firms. This review contributes to the academic literature by offering a consolidated framework for understanding how lean and ERP systems co-evolve in apparel manufacturing environments. It also provides actionable insights for practitioners, highlighting the importance of modular ERP design, middleware interoperability, cross-functional training, and leadership-driven cultural transformation. Ultimately, the findings.

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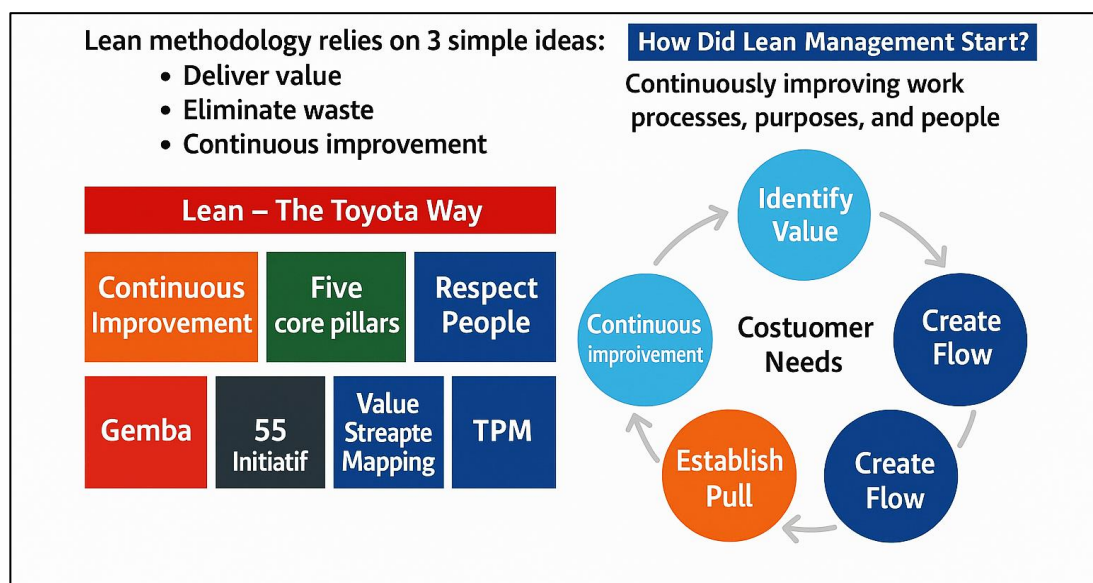
Keywords

Lean manufacturing, ERP integration, Apparel industry, Process efficiency, Production planning, Inventory management;

INTRODUCTION

Single nucleotide polymorphisms (SNPs), defined as variations at a single nucleotide position in Lean manufacturing, rooted in the Toyota Production System, is a structured approach focused on minimizing waste while maximizing productivity (Chen et al., 2019). Its implementation involves systematic identification and elimination of non-value-adding activities across production processes, primarily through tools such as value stream mapping, just-in-time (JIT), 5S, total productive maintenance (TPM), and continuous improvement or kaizen (Forno et al., 2021). Within the apparel sector an industry characterized by high labor intensity, short product life cycles, and volatile consumer demand lean principles have emerged as essential for maintaining competitiveness and cost-effectiveness (Haseeb et al., 2019). Studies reveal that lean practices in apparel manufacturing reduce inventory costs, increase floor efficiency, and enhance product quality (Lu, 2017). Notably, lean implementation addresses overproduction, defects, waiting time, unnecessary motion, and excess processing core inefficiencies typical in garment production (Kang & Park, 2012). As demand for fast fashion grows, lean tools enable manufacturers to improve time-to-market without compromising quality or labor compliance. Hence, lean manufacturing not only enhances process agility but aligns operational capabilities with consumer-centric value delivery in global apparel supply chains (Imran et al., 2018).

Figure 1: Foundations and Evolution of Lean Management: Core Pillars and the Value Creation Cycle



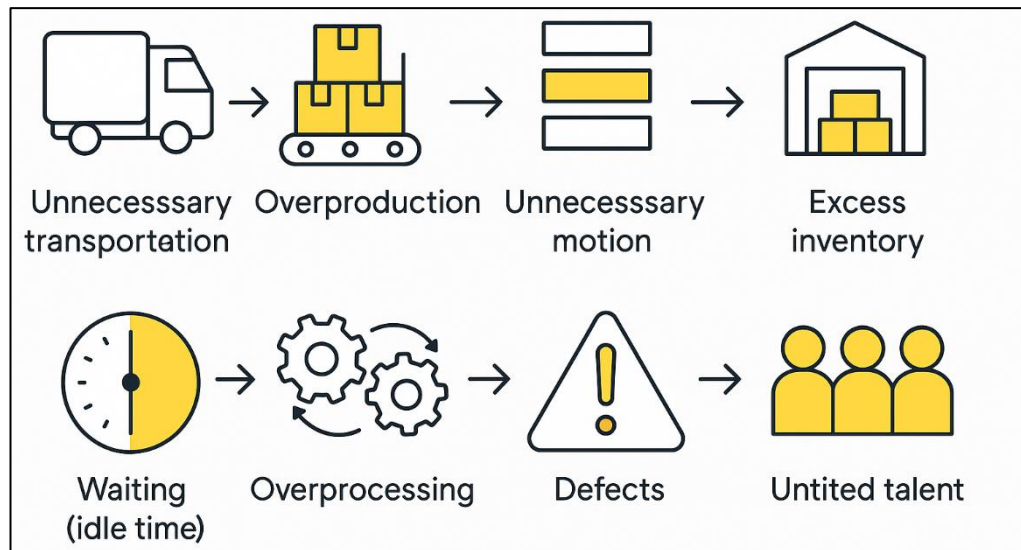
Enterprise Resource Planning (ERP) systems are integrated platforms that manage core business processes such as finance, procurement, production, and inventory in real time through a central database. These systems facilitate information flow and enable visibility across departmental boundaries, which is critical for coordination in apparel manufacturing where diverse functions like design, sourcing, production, and distribution must align (Surjit et al., 2016). The dynamic nature of the apparel industry where seasonal variations, short lead times, and fluctuating raw material prices dominate necessitates robust ERP systems to ensure seamless planning and execution (Hall et al., 2013). ERP systems contribute to real-time decision-making and allow for timely responsiveness to market changes, which is vital in the context of global sourcing and just-in-time inventory strategies. In particular, apparel firms benefit from ERP in managing complex supply networks, integrating supplier and customer data, and synchronizing operations across geographically dispersed facilities. Implementations in garment factories have shown improvements in order tracking, procurement accuracy, and demand forecasting (Nayak et al., 2015). Moreover, studies have reported enhanced material requirement planning (MRP), standardized reporting, and reduced production lead times as primary outcomes of ERP

deployments in textile and apparel firms (Saggiomo et al., 2016). Although traditionally viewed as separate paradigms one operational and the other informational recent literature emphasizes the synergy between lean manufacturing and ERP systems. Lean seeks to improve flow and eliminate waste, while ERP offers centralized control and data consistency; together, they offer a dual mechanism for process optimization (Ren et al., 2020). For instance, lean techniques such as kanban and pull systems can be digitally enabled through ERP functionalities, ensuring material availability aligns with real-time demand signals (Aksoy, 2017). Moreover, the analytical capabilities of ERP provide metrics and dashboards necessary for lean performance monitoring, root cause analysis, and decision-making (Ribeiro et al., 2020). In apparel manufacturing, where shop floor discipline must co-exist with rapid changes in design and sourcing, integrating lean practices with ERP helps in synchronizing production schedules with procurement, sales, and logistics (Liutkevičienė et al., 2022). Studies show that organizations achieving successful lean-ERP integration experience benefits such as shorter lead times, lower inventory levels, improved product quality, and higher on-time delivery rates (Cuevas-Vargas et al., 2020; Tang et al., 2020). Additionally, this integration fosters end-to-end visibility, which is essential for responsive manufacturing systems that need to quickly adapt to customer specifications. Process efficiency defined as the optimal use of resources to achieve production goals with minimal waste is a critical performance indicator in the apparel sector (Jituri et al., 2018). Given the industry's reliance on time-sensitive production cycles, driven by trends and rapid product turnover, even marginal improvements in efficiency translate into significant cost savings and market responsiveness. Apparel companies face constant pressure to deliver high-quality garments quickly while controlling overheads, reducing work-in-progress (WIP), and maintaining sustainability standards (Lizotte-Latendresse & Beauregard, 2018). Lean and ERP, when applied concurrently, provide the operational agility and data intelligence required to identify bottlenecks, eliminate redundancies, and enhance throughput. The literature reveals that firms leveraging these tools jointly report greater standardization of production procedures, streamlined workflows, and reduced cycle times (Hakim et al., 2022). In mass customization and private label manufacturing common in fashion retail such efficiency gains are particularly valuable, enabling flexible production with minimal resource waste. Furthermore, the ability to generate real-time operational metrics through ERP systems supports the continuous improvement culture promoted by lean. Despite the conceptual alignment between lean and ERP, their integration often encounters substantial barriers (Haseeb et al., 2019). Several studies highlight issues such as resistance to change, lack of cross-functional communication, and insufficient training as significant hurdles in implementation. The apparel industry, in particular, faces unique organizational constraints including fragmented supply chains, fluctuating labor skills, and capital limitations that complicate integrated deployments (Kamalulzaman et al., 2021; Maldonado-Guzmán et al., 2019). ERP systems typically follow a rigid structure requiring standardization, while lean encourages flexible and iterative improvement a dichotomy that, if unmanaged, can result in process misalignment. Additionally, some ERP implementations inadvertently introduce complexity or "process clutter," which contradicts the lean philosophy of simplification (Haseeb et al., 2019). A firm's readiness for such integration is contingent upon factors such as leadership commitment, IT infrastructure, change management capabilities, and lean maturity. Effective integration strategies must therefore encompass employee involvement, phased rollouts, cross-functional teams, and continuous training. Studies also advocate for the alignment of ERP modules with lean workflows from the onset, rather than as an afterthought, to ensure coherence and synergy (Haseeb et al., 2019; Kamalulzaman et al., 2021).

The international significance of lean and ERP integration is most evident in global apparel hubs like Bangladesh, Vietnam, India, and Turkey, where large-scale manufacturing drives national exports and employment (Maldonado-Guzmán et al., 2019). In these regions, manufacturers are increasingly compelled to meet stringent buyer requirements related to cost, quality, and delivery commonly referred to as the "triple constraint". As a result, factories are adopting lean-ERP models to remain competitive in global value chains. Research from Asian manufacturers shows that lean tools like standardized work, kanban, and takt time are being digitized and monitored through ERP platforms to ensure conformance and traceability. Case studies from Bangladesh reveal

substantial efficiency improvements such as 20-30% reductions in cycle time after lean and ERP adoption (Lindegren et al., 2022). Similarly, Indian apparel firms have utilized SAP-based ERP systems alongside Six Sigma and lean audits to reduce quality defects and improve order fulfilment. In Latin America and Eastern Europe, ERP has facilitated compliance with lean requirements imposed by EU and US buyers. These developments underscore the role of integrated process tools in bridging operational gaps between low-cost production and high-value market demands (Issau et al., 2021).

Figure 2: The Eight Wastes in Lean Manufacturing: Identifying Non-Value-Adding Activities

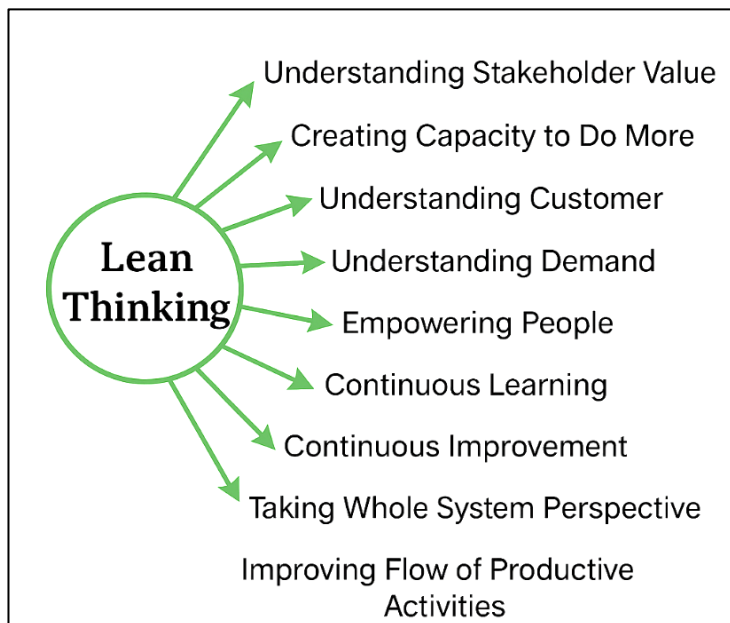


While a growing body of research has independently explored lean manufacturing and ERP systems, there is a notable gap in systematic reviews that synthesize their joint application in the context of apparel sector process efficiency (Visser, 2020). Most existing literature offers case-specific findings or tool-focused assessments without providing a holistic analysis of integration frameworks, performance metrics, or contextual variables such as industry structure and organizational culture (Heuvel & Bondarouk, 2017). Moreover, the heterogeneity in implementation strategies shaped by firm size, geography, and buyer requirements calls for a structured synthesis to identify patterns, challenges, and outcomes (Rane & Narvel, 2022). A systematic review offers methodological rigor and transparency in aggregating empirical findings, evaluating methodological quality, and identifying conceptual linkages. By focusing specifically on apparel manufacturing, this review contributes to both academic scholarship and industry practice, highlighting effective practices and guiding implementation choices. Furthermore, the intersection of lean and ERP holds significant implications for supply chain coordination, digital transformation, and sustainability critical domains in apparel production and trade (Pestana et al., 2020). This review, therefore, aims to systematically analyze the literature concerning lean-ERP integration in apparel to provide a comprehensive understanding of its role in improving process efficiency.

LITERATURE REVIEW

The integration of Lean Manufacturing and Enterprise Resource Planning (ERP) within the apparel manufacturing sector has emerged as a transformative approach for enhancing operational efficiency and strategic responsiveness. The body of literature addressing these paradigms is vast, yet often fragmented, with studies focusing separately on lean principles, ERP system functionalities, or sector-specific applications (Solaimani et al., 2019). A systematic review of this integrated domain is essential to bridge these knowledge silos and provide a consolidated perspective on how lean and ERP interact, complement, and, at times, challenge each other in apparel production environments.

Figure 3: Core Principles of Lean Thinking: A Systemic Approach to Value Creation and Continuous Improvement

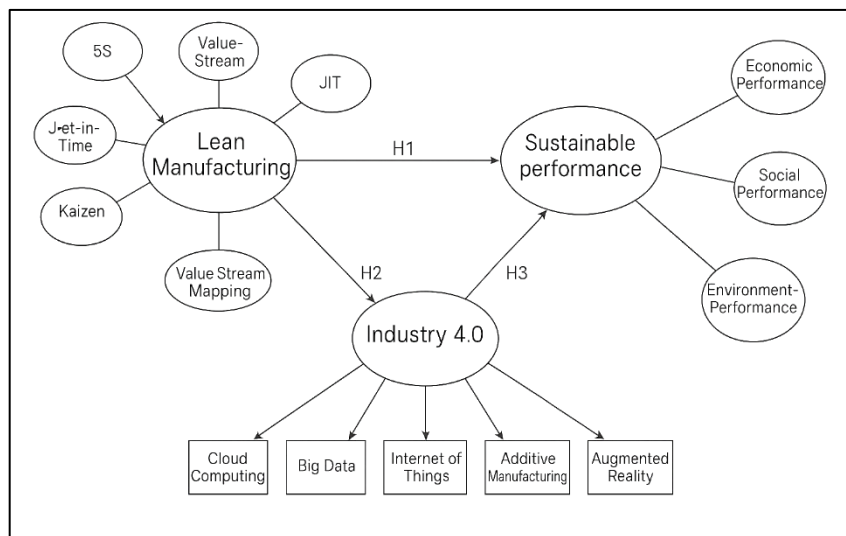


This section presents a structured examination of existing scholarly research relevant to the topic. (Khodeir & Othman, 2018). It begins with a foundational overview of lean and ERP, each treated in its domain-specific evolution within manufacturing and IT management literature. The review then narrows its focus to empirical studies and case analyses in the apparel sector, which has unique characteristics such as high SKU variability, seasonal demand, short lead times, and global supply chain dependency. Sartal et al. (2018) emphasis is placed on identifying patterns of success, points of resistance, integration models, and quantifiable impacts. This literature review is organized into thematically defined sub-sections that explore conceptual

foundations, empirical trends, implementation models, and contextual considerations that influence lean-ERP integration. The scope covers peer-reviewed journal articles, industrial case studies, and meta-analyses published from the early 2000s to the present. Depending on, Nicholas (2018) a synthesis of methodologies, findings, and theoretical contributions will provide the groundwork for identifying gaps in the literature and justifying the systematic review.

Conceptual Foundations of Lean Manufacturing in Apparel

Lean thinking, originating from the Toyota Production System (TPS), represents a comprehensive philosophy centered on minimizing waste while maximizing customer value. Initially formulated in Japan during the mid-20th century, the TPS emphasized efficiency through standardization, flow synchronization, and respect for people (Hazarika et al., 2019). The foundational work of Womack and Jones (1996) later codified these principles into five core tenets: specify value, identify the value stream, create flow, establish pull, and pursue perfection. These lean pillars, when applied to manufacturing sectors outside of automotive contexts, were adapted to meet distinct operational requirements. In labor-intensive industries such as apparel, the focus on eliminating the “seven wastes” overproduction, inventory, motion, waiting, transportation, defects, and over-processing has become instrumental in driving efficiency (Salhie et al., 2018). The sector’s reliance on manual operations, frequent design changes, and volatile demand patterns makes it particularly receptive to lean approaches (Widodo et al., 2021). As noted by Santos et al. (2023), lean methodologies allow apparel manufacturers to respond quickly to market changes while maintaining quality standards and cost efficiency. Moreover, researchers such as Galankashi et al. (2019) have emphasized that lean implementation in apparel promotes agility by aligning production with real-time demand and reducing non-value-adding activities across the shop floor. As lean evolved globally, scholars recognized the need to tailor its practices to fit local

Figure 4: Conceptual Foundations of Lean manufacturing in Apparel

reduction and efficiency improvement. Among the most widely applied tools are 5S (Sort, Set in order, Shine, Standardize, Sustain), Just-in-Time (JIT), Value Stream Mapping (VSM), Single-Minute Exchange of Die (SMED), and Kaizen (continuous improvement) (Mrugalska et al., 2020). The 5S system fosters workplace organization and discipline, which is especially crucial in garment production where large volumes of materials and accessories are handled (Conte, 2020). JIT ensures materials are only procured and used when required, thereby minimizing inventory and freeing up working capital an important consideration in the cash-sensitive apparel industry (Feld, 2000). VSM allows manufacturers to map and analyze each step in the production process to identify bottlenecks and redundant operations. SMED reduces changeover times between garment styles, enabling faster response to fashion trends and small batch production. Kaizen supports ongoing, incremental improvements by empowering frontline employees to identify inefficiencies. Empirical studies confirm the effectiveness of these tools in improving operational performance. For instance, Hines, Holweg, and Rich (2004) demonstrated that lean implementations reduced cycle time and increased throughput in apparel production environments. Similarly, Adam and Alarifi (2021) reported a 25% increase in productivity and significant reductions in rework and floor space utilization after lean tool deployment. Bolinao, (2009) documented substantial work-in-progress (WIP) reductions following VSM and JIT adoption in textile firms. Metrics used to evaluate lean success include WIP levels, first-pass yield, labor productivity, machine utilization, and order cycle time (Obulam & Rybkowski, 2021). In developing economies, the application of these tools has also shown measurable improvements in compliance with international quality and labor standards. The success of lean tools in the apparel industry thus lies not only in their technical capabilities but in their adaptability to dynamic manufacturing contexts. Despite the demonstrated benefits of lean manufacturing, its adoption within the apparel sector is often constrained by multiple organizational and environmental factors (Dabić et al., 2019). One of the most persistent challenges is workforce variability, particularly in regions where labor turnover is high, and training levels are inconsistent. The seasonal nature of apparel production exacerbates this issue, as temporary labor is frequently employed to meet peak demand, limiting the continuity required for successful lean culture development. Furthermore, supply chain dependencies especially in offshore manufacturing hubs pose significant risks to lean systems. Just-in-Time principles rely heavily on predictable supplier performance, yet apparel suppliers often face infrastructural bottlenecks, import delays, or capacity constraints (Rogerson et al., 2022).

Another critical barrier is the entrenched traditional culture within many apparel factories, where hierarchical management styles, resistance to change, and weak process documentation inhibit the cross-functional collaboration required for lean success (Majumdar et al., 2021). Many small-

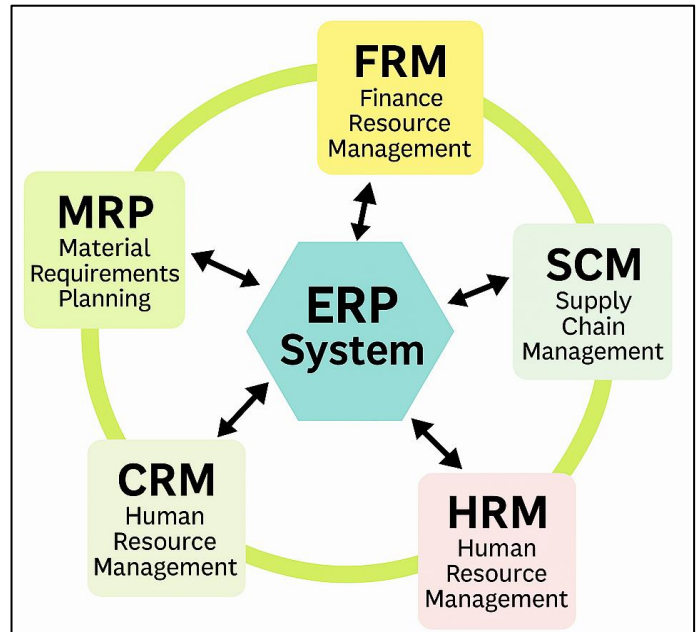
and medium-sized enterprises (SMEs), which dominate apparel manufacturing in developing countries, lack the financial and human resources to invest in lean training, tools, or external consultancy support (Ye et al., 2018). Case studies from India and Bangladesh highlight that without top-management commitment and employee empowerment, lean transformations are often superficial or unsustainable. Moreover, Manca et al. (2018) have observed that even where lean tools are introduced, they are not always integrated into the broader business processes or supported by performance measurement systems. Hence, lean adoption in apparel is not only a technical initiative but a socio-cultural transformation that must overcome structural and behavioral resistance. Lean manufacturing in apparel cannot be viewed through a one-size-fits-all lens; rather, it is shaped by the specific economic, cultural, and operational contexts in which garment factories operate (Jituri et al., 2018). The adaptation of lean from its automotive origins to labor-intensive, fashion-driven production systems illustrates its flexibility but also its dependency on contextual fit. Apparel production, characterized by small order sizes, quick turnaround, and high customization, demands a modified lean approach that emphasizes flexibility alongside standardization (Jayaram, 2016). For example, while automotive plants benefit from long production runs, apparel factories must frequently switch styles, requiring lean tools like SMED and mixed-model scheduling to be reimaged for short-cycle manufacturing (Liutkevičienė et al., 2022). This necessity is echoed by empirical evidence showing that firms with a strong culture of continuous improvement, supported by flexible ERP systems and cross-functional teams, achieve more sustainable lean outcomes (Majumdar et al., 2021). Moreover, successful lean implementation depends on the alignment of organizational goals, workforce engagement, and performance measurement. Studies suggest that lean should not be pursued as a standalone initiative but embedded into the broader strategic framework, including supplier collaboration, product lifecycle management, and customer responsiveness (Carvalho et al., 2019). In this regard, lean becomes both a philosophy and a set of tools, working synergistically with digital systems and human resource practices to deliver lasting gains. Importantly, the literature indicates that the apparel sector's constraints such as fragmented supply chains, capital limitations, and informal labor practices must be considered not as impediments but as parameters for redesigning lean interventions (Bamfo & Kraa, 2019). The body of research thus underscores that lean in apparel is not merely a transfer of industrial engineering techniques but a reconfiguration of operational thinking tailored to the realities of globalized, consumer-driven fashion markets.

Theoretical Frameworks of ERP Systems in Manufacturing

Enterprise Resource Planning (ERP) systems evolved from earlier Material Requirements Planning (MRP) frameworks, which were originally developed in the 1960s and 1970s to assist with inventory control and production scheduling (Verhees & Meulenbergh, 2004). MRP systems focused on determining material requirements based on a master production schedule but lacked integration across other business functions. The subsequent development of MRP II introduced capacity planning and shop floor control, paving the way for the modern ERP system, which integrates manufacturing with functions such as finance, procurement, HR, and customer relationship management (Bamfo & Kraa, 2019). ERP systems provide a centralized database that ensures real-time data sharing across functional silos, enabling a unified view of operations. This evolution was critical for manufacturers seeking to respond to globalization, increasing product complexity, and just-in-time delivery demands (Majumdar et al., 2021). The architecture of ERP systems is typically modular, comprising integrated units such as sales and distribution, production planning, materials management, and financial accounting. Each module contributes to a seamless flow of data, reducing errors and redundancies while enhancing interdepartmental coordination (Liutkevičienė et al., 2022). As ERP matured, systems began incorporating web interfaces, cloud-based platforms, and advanced analytics to further improve scalability and decision-making capabilities. This evolution has been driven by both technological advances and strategic imperatives, as firms increasingly use ERP systems not just for operational control but also for gaining competitive advantage through process integration and data-driven agility (Jayaram, 2016). As ERP systems become indispensable to modern manufacturing, their design continues to evolve toward greater modularity, usability, and alignment with lean, agile, and customer-centric paradigms. In the apparel sector characterized by rapid product turnover,

seasonality, and a high variety of styles ERP systems serve uniquely tailored purposes beyond those in traditional manufacturing (Jituri et al., 2018). Unlike automotive or electronics industries, apparel production involves high SKU variability, size and color combinations, and frequent design changes, all of which demand specialized ERP configurations. Leading ERP platforms in apparel incorporate modules that manage style creation, bill of materials (BOM) for multiple variants, cut order planning, and fabric utilization (Dabić et al., 2019). These capabilities are critical for controlling costs and avoiding overproduction, which is common in fast fashion production cycles. Furthermore, ERP systems in apparel often include features for sample management, seasonal forecasting, and compliance tracking functions essential to maintain delivery timelines and quality assurance in global sourcing environments (Bolinao, 2009). Another significant application is vendor management and supply chain traceability. Apparel manufacturers often rely on multiple subcontractors and suppliers across different regions, creating a complex sourcing network (Adam & Alarifi, 2021). ERP systems help firms track raw materials from origin to finished goods, monitor vendor performance, and ensure regulatory compliance, such as REACH, OEKO-TEX, or labor law certifications. This traceability not only enhances transparency but also supports corporate social responsibility (CSR) reporting, now a requirement for many global brands. Additionally, ERP assists in production planning by linking style orders to fabric and trim requirements, enabling timely procurement and production sequencing (Issau et al., 2021). These functionalities are indispensable in managing short lead times and aligning manufacturing output with volatile demand. Studies have shown that apparel firms using ERP achieve better order accuracy, lower raw material wastage, and higher supplier compliance compared to those relying on fragmented or manual systems (Maldonado-Guzmán et al., 2019). Empirical evidence from apparel manufacturing firms demonstrates that ERP implementation yields measurable performance improvements across operational, financial, and compliance dimensions (Kamalulzaman et al., 2021; Maldonado-Guzmán et al., 2019). One of the most commonly reported outcomes is increased procurement accuracy. By centralizing purchase requisitions, linking them to production plans, and providing real-time inventory visibility, ERP systems reduce overordering, stockouts, and procurement delays. In textile and apparel firms, this has led to better alignment between material availability and production schedules, ultimately lowering material handling costs and reducing production halts. Similarly, ERP contributes to cycle time reduction by automating routine processes such as order entry, invoice generation, and quality checks, which speeds up throughput from order placement to delivery (Haseeb et al., 2019). Data centralization and visibility are other core benefits emphasized in ERP literature. With all functional data stored in a unified database, decision-makers gain timely insights into shop floor performance, order status, and resource utilization, enabling proactive intervention and continuous improvement. This is especially valuable in apparel manufacturing, where changeovers, material substitutions, and urgent rework often occur. ERP dashboards and key performance indicators (KPIs) provide a data-rich foundation for lean initiatives, process audits, and compliance reporting (Cuevas-Vargas et al., 2020). In large-scale implementations, particularly in Asia's apparel hubs, firms have reported improvements in on-time delivery rates, lower rework percentages, and enhanced

Figure 5: Key Functional Modules of ERP Systems in Manufacturing Environments

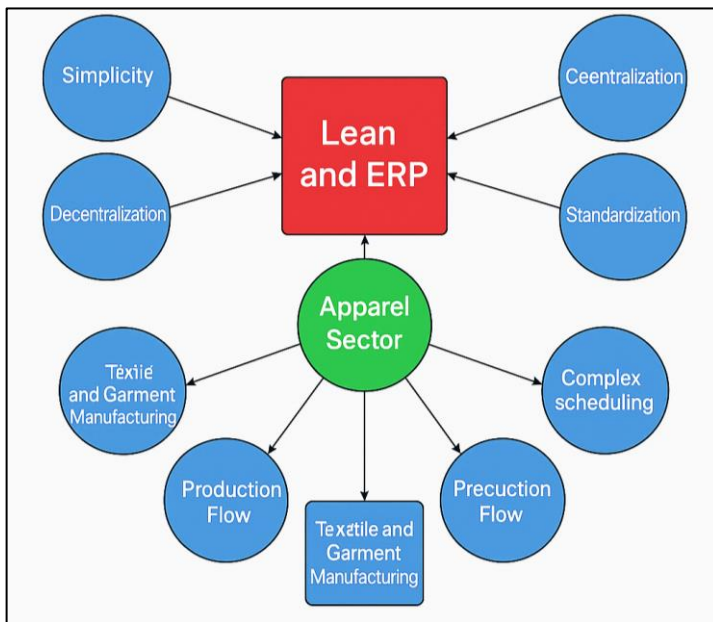


coordination between departments. Furthermore, the analytical capabilities of ERP systems such as cost analysis, trend forecasting, and exception reporting—support strategic decision-making and agile manufacturing. Beyond immediate operational benefits (Hakim et al., 2022), ERP systems play a strategic role in shaping long-term competitiveness in the apparel sector. By enabling data-driven decision-making, fostering cross-functional alignment, and facilitating global supply chain integration, ERP supports firms in responding to volatile market conditions and stringent buyer requirements. For example, in export-oriented garment units, ERP helps navigate complex customs documentation, buyer-specific labeling, and international logistics by integrating these processes into a single platform (Haseeb et al., 2019). The visibility and standardization afforded by ERP are also essential for meeting the compliance expectations of global retailers, particularly in areas such as ethical sourcing, environmental footprint reporting, and labor audits. ERP's integration with customer relationship and supply chain modules enables better demand forecasting, dynamic pricing, and personalized order configuration, which are critical in today's fast-fashion landscape. This level of responsiveness is vital for private-label manufacturers that operate under tight retail windows and cannot afford inventory misalignment. Moreover, ERP supports strategic supplier development by analyzing vendor performance, delivery reliability, and defect rates, thereby facilitating continuous improvement in procurement practices (Hakim et al., 2022). Additionally, the growing convergence of ERP with other technologies such as RFID, IoT, and cloud computing positions it as a backbone for digital transformation in the apparel sector.

Lean and ERP

The compatibility between lean manufacturing and ERP systems has been the subject of extensive debate, as scholars and practitioners examine whether these two frameworks are inherently complementary or fundamentally in conflict (Jayaram, 2016). Lean manufacturing emphasizes simplicity, decentralization, and flexibility, while ERP systems are often characterized by centralization, standardization, and procedural rigidity. This philosophical divergence has raised questions about whether ERP systems support or hinder the lean objective of waste elimination (Liutkevičienė et al., 2022). For instance, ERP's batch-processing logic may contradict lean's preference for one-piece flow and pull-based production systems. However, other studies argue that when properly configured, ERP can complement lean by enabling greater visibility, coordination, and data-driven decision-making across functions. Hybrid integration models have emerged as viable solutions to reconcile these tensions. Case studies suggest that implementing lean on the shop floor and ERP at the organizational level can create a balanced approach that leverages the strengths of both systems. For example, in textile and garment manufacturing environments, ERP can manage complex scheduling and procurement activities while lean governs production flow and continuous improvement efforts. Chen et al. (2019) show that organizations achieving strategic alignment between lean principles and ERP functionalities report enhanced performance, including reduced lead times and improved customer responsiveness. These hybrid systems require thoughtful planning and customization, particularly in dynamic sectors like apparel, where both lean flexibility and ERP traceability are essential for success.

Contrary to the belief that ERP systems obstruct lean initiatives, a growing body of research supports the view that ERP can serve as a powerful enabler of lean practices when implemented with strategic alignment. ERP provides the digital infrastructure necessary to support lean tools such as kanban systems, takt time monitoring, production leveling (heijunka), and value stream mapping (Alcayaga et al., 2019). For instance, electronic kanban systems integrated into ERP platforms can automate reorder points and inventory replenishment based on real-time consumption, aligning closely with lean's pull-production logic. Similarly, ERP dashboards and

Figure 6: Lean Principles and ERP Systems in the Apparel Sector

standardized data entry and real-time communication between production, procurement, and inventory departments key enablers of synchronized lean flow. By automating non-value-adding processes such as manual data transfer and documentation, ERP helps maintain focus on lean goals. Thus, when designed and deployed with lean principles in mind, ERP can elevate operational excellence and contribute to a culture of continuous process improvement (Liutkevičienė et al., 2022).

While ERP can enable lean practices under ideal conditions, numerous studies caution that its implementation often introduces complexity that can hinder lean outcomes. This phenomenon, referred to as “process clutter,” results when ERP systems impose overly rigid workflows that conflict with lean’s emphasis on simplicity, adaptability, and front-line decision-making. Standardized ERP modules may not accommodate the informal, dynamic adjustments that lean shop floors often require, particularly in the apparel sector, where variability in fabric, styles, and seasonal orders necessitates constant operational tweaks (Chen et al., 2019). In these cases, the drive to automate every transaction or data flow can create unnecessary procedures that increase administrative workload and reduce the flexibility needed to respond to real-time issues. Further, ERP systems often prioritize planning and control over learning and adaptation, leading to centralization that may suppress the problem-solving capabilities of decentralized lean teams. Scholars have documented cases where the rigidity of ERP slowed down decision-making and stifled local innovation, particularly in production environments requiring high agility. For example, observed that standardized ERP reports sometimes conflicted with the visual and intuitive management tools preferred in lean settings. In some apparel factories, line managers found it difficult to reconcile ERP-driven batch production schedules with lean flow lines designed for one-piece movement (Jayaram, 2016). The lack of customization and user involvement during ERP design stages further contributes to system misalignment and underutilization. These findings suggest that ERP systems, if implemented without lean-sensitive design, risk institutionalizing inefficiencies rather than eliminating them (Liutkevičienė et al., 2022). The synthesis of literature on ERP and lean integration underscores a nuanced relationship—neither entirely complementary nor purely oppositional, but conditional on design, implementation, and contextual fit. ERP provides structure, visibility, and discipline, while lean offers adaptability, employee engagement, and waste minimization. Studies show that firms that succeed in balancing these forces tailor ERP functionalities to support rather than dictate lean workflows (Chen et al., 2019). This involves aligning ERP modules with value streams, customizing reporting

analytics modules facilitate performance tracking and root cause analysis, both central to continuous improvement (kaizen) and total quality management (Chen et al., 2019). In apparel manufacturing, where lean emphasizes minimizing work-in-progress (WIP), streamlining workflow, and ensuring short production cycles, ERP systems provide timely data that help monitor order fulfillment, quality metrics, and supplier delivery performance. Several studies show that firms using ERP to complement lean initiatives see improvements in lead time, defect rates, and on-time delivery (Alcayaga et al., 2019). For example, the use of ERP-integrated lean systems to achieve takt-time conformance in a garment factory, leading to improved labor efficiency and reduced overtime costs. Moreover, ERP platforms support

tools for shop floor needs, and enabling real-time feedback loops that inform both strategic and operational decisions. In the apparel sector, where production systems must accommodate rapid style changes and fluctuating order volumes, such balance is particularly critical. Frameworks proposed by Jayaram (2016) advocate for ERP-lean integration strategies that begin with lean process mapping before ERP deployment, ensuring that digital systems mirror streamlined, value-adding flows. Other scholars suggest phased rollouts, starting with lean pilots supported by minimal ERP modules, gradually scaling integration as maturity increases. Case examples from apparel manufacturers in Asia reveal that firms using modular ERP systems with configurable workflows report higher alignment and greater lean performance compared to those deploying off-the-shelf systems. Cross-functional involvement, ongoing training, and continuous feedback mechanisms are cited as essential enablers for sustaining this integration. Therefore, successful lean-ERP synergy in apparel hinges not on choosing one paradigm over the other, but on designing a system architecture and organizational culture that blend structure with responsiveness. This integrative mindset transforms ERP from a static control system into a dynamic enabler of lean transformation.

Integration Models and Implementation Approaches

The debate over whether lean practices or ERP systems should be implemented first in manufacturing organizations has resulted in two prominent sequential integration models: lean-first and ERP-first (Ahmed et al., 2022). A lean-first approach typically focuses on stabilizing and optimizing processes before automating them, ensuring that ERP systems are built upon streamlined operations. This model aligns with lean's philosophy of eliminating waste prior to digitization and is considered advantageous in sectors with complex, labor-intensive workflows like apparel manufacturing (Mahmud et al., 2022). On the other hand, ERP-first implementations prioritize establishing system-wide visibility, process standardization, and data integration before applying lean tools (Mahfuj et al., 2022). Proponents argue that ERP-first facilitates more effective lean rollouts by ensuring accurate data and cross-functional coordination (Majharul et al., 2022; Masud, 2022).

Comparative studies offer mixed results. Samaranayake, Kolberg and Zühlke (2015) found that lean-first organizations experienced more sustainable performance improvements and stronger cultural alignment, especially in decentralized manufacturing setups. In contrast, Jituri et al., (2018) reported that ERP-first firms achieved faster financial returns due to immediate gains in inventory visibility and procurement control. The apparel sector benefits more from a lean-first sequence because process flexibility and quick changeovers are necessary before ERP standardization (Hossen & Atiqur, 2022; Kumar et al., 2022). Conversely, in capital-intensive industries with complex BOMs and global sourcing, ERP-first is preferred to gain control over scattered operations. Some manufacturers adopt a hybrid or parallel approach, deploying lean and ERP in tandem, with cross-feedback loops to harmonize digital capabilities with operational routines (Katuri, 2025). Overall, the choice of sequencing must align with organizational maturity, sector-specific complexity, and the adaptability of both workforce and leadership. The design of integration frameworks and system architectures plays a critical role in aligning ERP systems with lean manufacturing processes. Standardized integration frameworks often advocate for aligning

Figure 7: Sequential and Hybrid Integration Models for Lean and ERP Implementation in Manufacturing



ERP modules with lean value streams mapping each digital transaction to a specific activity in the production workflow to ensure that technology supports rather than disrupts flow (Arafat Bin et al., 2023; Soheli et al., 2022). For example, an ERP-integrated kanban system should mirror physical inventory pull mechanisms on the shop floor, enabling real-time replenishment and reducing stockouts or overproduction. This alignment enhances visibility and traceability, which are crucial for apparel firms dealing with multiple SKUs, color variants, and rapid order changes (Chowdhury et al., 2023; Kolberg & Zühlke, 2015). The literature also emphasizes the importance of flexible architectures, particularly through modular ERP systems, middleware solutions, and cloud-based platforms. Middleware acts as a bridge between legacy lean tools and new ERP modules, allowing for seamless data exchange without forcing rigid standardization (Jahan, 2023). This is particularly beneficial in SMEs and apparel factories where production processes evolve frequently and require adaptable IT infrastructure (Jituri et al., 2018; Maniruzzaman et al., 2023). Cloud ERP systems offer further flexibility, enabling remote access, scalable deployments, and lower upfront costs advantages for apparel firms operating across multiple geographic locations (Hossen et al., 2023). Furthermore, standardized APIs and plug-in modules enhance interoperability between lean software (e.g., VSM tools or shop floor control systems) and ERP platforms like SAP, Oracle, or Infor. As the complexity of apparel production networks increases, modular, cloud-enabled, and middleware-supported ERP architectures are becoming vital enablers of lean-ERP integration strategies (Nicholas, 2018; Alam et al., 2023).

The methodology chosen to implement ERP and lean practices significantly impacts the success of their integration (Roksana, 2023). Three main approaches dominate the literature: agile, phased, and big-bang. The agile methodology, derived from software development, promotes iterative deployment (Jayaram, 2016; Sarker et al., 2023), cross-functional collaboration, and continuous feedback traits that resonate with lean's kaizen philosophy. In agile implementations, ERP features are rolled out incrementally in short cycles, allowing process improvements to evolve in tandem (Shahan et al., 2023; Solaimani et al., 2019). This is especially effective in apparel firms where business requirements shift frequently due to fashion cycles, seasonal demand, and buyer specifications. The phased approach involves deploying ERP and lean modules in a staged sequence often by department, business function, or geographic location. This method reduces implementation risks and allows teams to adapt gradually (Santos et al., 2023; Siddiqui et al., 2023). For example, a firm might begin with inventory management, followed by production planning, and finally integrate with finance and quality control systems. Several apparel manufacturers have reported success using this method, as it facilitates learning, limits disruptions, and allows parallel lean training programs (Chen et al., 2019; Tonoy & Khan, 2023). In contrast, the big-bang approach involves deploying the full ERP suite at once, requiring extensive planning, coordination, and training. While it can deliver immediate standardization and integration benefits, it also carries a high risk of failure due to organizational resistance, data migration errors, or process misalignments. Effective project management is essential across all methodologies. Tools such as Gantt charts, critical path method (CPM), and integrated project dashboards help monitor timelines, costs, and resource allocation (Cobo et al., 2012).

Moreover, stakeholder engagement especially involving production managers, IT staff, and line workers is a recurring success factor. Training, change management strategies, and feedback mechanisms must be embedded from the start to build ownership and minimize resistance. These methodologies, when tailored to organizational capacity and industry dynamics, can significantly enhance the success of lean-ERP integration. Implementation strategies for lean-ERP integration in apparel manufacturing must be contextualized to reflect industry-specific challenges such as product variability, labor dependence, and fast-changing demand. The literature reveals that firms adopting adaptive, context-sensitive approaches are more likely to achieve sustained performance improvements than those pursuing generic strategies. For instance, apparel manufacturers often benefit from phased ERP deployments accompanied by lean tool training, supported by middleware for transitional integration. This gradualism allows the alignment of standardized ERP modules with fluid, shop-floor lean practices without overwhelming the workforce or disrupting daily operations. Strategic frameworks must also integrate internal capability assessments and readiness diagnostics prior to implementation. Alcayaga et al.(2019)

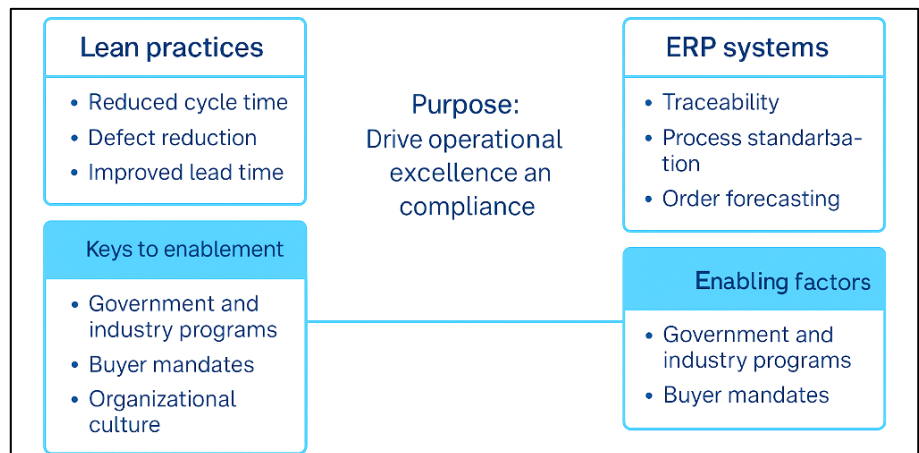
emphasize the need for ERP readiness models that assess organizational culture, IT infrastructure, and human capital. These frameworks help firms determine the optimal methodology (agile, phased, or big-bang) and identify potential risks early. Apparel firms operating in emerging economies often face infrastructural constraints, requiring creative use of cloud ERP, open-source platforms, and vendor collaboration to manage integration cost-effectively. Furthermore, agile project governance structures such as steering committees, sprint review boards, and cross-functional integration teams are critical to navigating the complexity of lean-ERP synchronization. A key insight across successful case studies is that integration is not merely a technical exercise but a socio-technical transformation. Engaging end users, building internal champions, and continuously validating ERP functionalities against lean objectives are critical enablers (Alcayaga et al., 2019; Liutkevičienė et al., 2022). Ultimately, implementation strategies that foster co-creation between lean and ERP stakeholders deliver the most robust, scalable, and sustainable performance gains in apparel sector operations.

Sector-Specific Evidence: Lean-ERP Integration in the Apparel Industry

Empirical evidence from global apparel manufacturing hubs such as Bangladesh, India, Vietnam, Turkey, and China reveals a diverse landscape of lean-ERP integration practices shaped by regional constraints, policy support, and buyer expectations (Solaimani et al., 2019). In Bangladesh, several ready-made garment (RMG) factories have reported adopting lean practices to address inefficiencies in production and ERP systems to comply with global sourcing requirements. Lean-ERP integration reduced cycle time by over 25% in a Bangladeshi apparel firm, while also improving buyer compliance documentation. ERP deployments aligned with Six Sigma and lean

frameworks led to defect reduction, process standardization, and improved on-time delivery in garment units (Santos et al., 2023). Vietnam and Turkey, as major exporters to the US and EU, respectively, have adopted lean-ERP models primarily to enhance traceability and meet fast fashion lead times. Vietnamese

Figure 8: Lean-ERP Integration Framework for Operational Excellence in the Apparel Industry



case studies show that ERP systems configured with lean-focused dashboards enabled production leveling and enhanced order forecasting (Chen et al., 2019). In China, large apparel firms have used lean-ERP integration to support mass customization, leveraging ERP's configuration-to-order modules alongside lean cells for agile response. The role of government in facilitating this integration is also noteworthy. In India and Bangladesh, government and trade association programs such as SMED workshops, lean training schemes, and ERP adoption subsidies have played a key role in encouraging digital-operational transformation. Moreover, global buyers increasingly mandate compliance with quality, labor, and environmental standards, prompting suppliers to adopt ERP for real-time audit trails and lean for ethical productivity. These country-specific studies underscore that lean-ERP integration is not a monolithic process but one deeply embedded in local institutional, economic, and supply chain contexts. Quantitative studies in the apparel sector affirm the tangible benefits of lean-ERP integration, with significant improvements reported across multiple key performance indicators (KPIs). Cost savings are among the most frequently cited outcomes. For example, a 30% reduction in manufacturing overheads after integrating ERP with lean scheduling tools in a knitwear factory. ERP alignment in Asian garment units contributed to an average 20% reduction in procurement costs due to better

inventory planning and supplier communication. [Cobo et al. \(2012\)](#) identified labor efficiency gains of up to 25% in Vietnamese firms that deployed ERP modules in parallel with value stream-based lean interventions. Lead time reduction is another widely measured impact. Firms saw cycle times drop by up to 40% when ERP-enabled real-time order tracking was synchronized with lean shop-floor execution. These reductions were particularly pronounced in export-oriented units operating under fast fashion constraints. Improvements in product quality have also been observed.

[Alcayaga et al. \(2019\)](#) noted a 15% decline in defect rates after ERP-integrated statistical process control (SPC) systems were paired with lean quality tools such as poke-yoke and root cause analysis. Comparative KPI studies by revealed significant gains in first-pass yield, customer satisfaction scores, and inventory turnover rates post-integration. Data centralization through ERP also supports timely reporting and decision-making, enabling more effective lean performance audits. These quantifiable outcomes validate the argument that lean-ERP synergy can yield operational excellence in apparel settings provided that tools are selected, configured, and managed with alignment to production goals and market requirements. The integration of lean manufacturing and ERP systems is not merely a technological or procedural exercise it is a profound organizational change initiative that demands shifts in culture, leadership, and workforce engagement. Several studies highlight the critical role of employee upskilling in determining the success of integration projects. Organizations with a strong emphasis on continuous learning and training achieve higher ERP utilization and lean maturity levels. Apparel manufacturers in Bangladesh and India have invested in structured training programs covering ERP navigation, lean tools like 5S and SMED, and cross-functional communication skills. This workforce development is vital in labor-intensive settings where front-line participation drives lean success and ERP adoption depends on user competence. Resistance to change remains a significant barrier. [Solaimani et al. \(2019\)](#) note that employees and middle managers often resist ERP systems due to fears of surveillance, job displacement, or loss of autonomy concerns that are compounded when lean initiatives restructure work roles.

[Cobo et al. \(2012\)](#) observed that leadership commitment and transparent communication were essential for overcoming resistance in Indian apparel plants. The presence of lean leadership defined by hands-on involvement, empowerment, and a focus on long-term process improvement was a strong predictor of successful cultural transformation. Change management frameworks are frequently recommended to guide lean-ERP transformation. These include Kotter's eight-step model and ADKAR (Awareness, Desire, Knowledge, Ability, Reinforcement), which offer structured pathways for mobilizing stakeholders and embedding change. Organizational culture also influences integration outcomes. Firms with collaborative, data-driven, and improvement-oriented cultures demonstrate higher alignment between ERP systems and lean goals. Thus, lean-ERP integration in apparel is as much about shifting mindsets and behaviors as it is about aligning systems and processes. The accumulated sector-specific evidence suggests that lean-ERP integration in apparel manufacturing is most effective when approached as a context-sensitive, multi-dimensional process. Rather than adopting generic best practices, successful firms tailor integration strategies to account for market positioning, labor dynamics, buyer mandates, and organizational readiness. Case studies from Bangladesh, India, Vietnam, and Turkey reveal that integration outcomes are strongly mediated by supply chain complexity, institutional support, and firm size. Small and medium enterprises (SMEs), which form the backbone of many apparel economies, often face resource constraints and require lightweight, modular ERP systems combined with basic lean tools to achieve stepwise improvement. The synthesis of literature indicates a clear pattern: successful lean-ERP integration hinges on dynamic capabilities such as sensing customer needs, reconfiguring internal processes, and learning through experimentation ([Alcayaga et al., 2019](#)). Government and industry-led programs can further support this integration by offering lean certification, ERP subsidies, and knowledge-sharing platforms. Metrics-driven accountability is also central. Firms that tie lean and ERP initiatives to specific KPIs such as takt time, defect rate, order fulfillment rate, and process downtime achieve more sustainable performance gains. Moreover, integration must span vertically across management layers and horizontally across departments to avoid siloed optimization. In

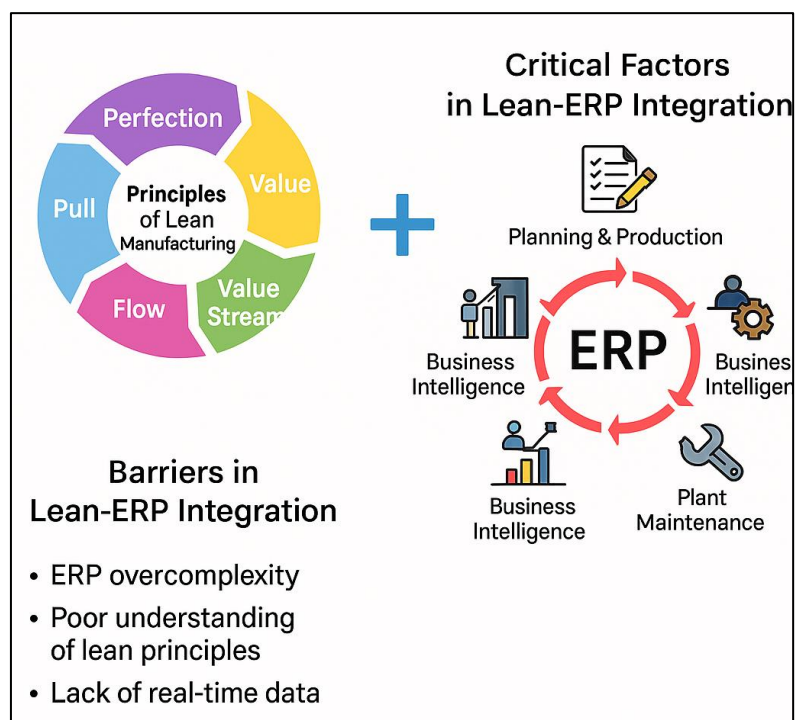
summary, lean-ERP integration in apparel manufacturing is shaped by unique sectoral variables and succeeds when supported by a confluence of technological, human, and institutional factors. The empirical richness of global case studies affirms that with proper alignment; this integration can serve as a robust vehicle for transforming apparel operations in line with global competitiveness and compliance standards (Santos et al., 2023)

Success Factors and Barriers in Lean-ERP Integration

Successful integration of lean manufacturing and ERP systems depends heavily on the organization's technical capabilities, particularly in terms of ERP customization, middleware adoption, and digital infrastructure readiness. Unlike traditional plug-and-play implementations, lean-ERP integration requires tailoring ERP modules to reflect lean logic, such as pull systems, takt time, and one-piece flow (Surjit et al., 2016). Standard ERP platforms often embody push-based planning and batch production paradigms, which must be reconfigured to support lean's just-in-time and demand-driven models (Hall et al., 2013). Middleware solutions have proven instrumental in bridging the gap between lean execution systems and ERP backbones. These integration layers facilitate communication between lean-focused tools such as kanban boards and production-level tracking and enterprise-level ERP applications, ensuring seamless data flows and system interoperability (Saggiomo et al., 2016).

Cloud-based ERP systems also offer technical flexibility, especially for apparel firms with distributed manufacturing units or limited IT infrastructure (Aksoy, 2017). Their modular design, remote access capabilities, and cost-effective deployment models make them attractive for small and medium-sized enterprises (SMEs) seeking lean-ERP synergy. In contrast, firms relying on legacy systems often struggle with limited integration capabilities, data silos, and delayed processing, which undermine lean's emphasis on real-time responsiveness. Scholars such as emphasize that IT infrastructure must not only support technical integration but also facilitate scalable, lean-aligned workflows. In apparel manufacturing, where product variety and style changes are frequent, the ability to reconfigure ERP settings dynamically such as revising BOMs, altering batch sizes, or updating shop floor layouts is essential (Ribeiro et al., 2020). Ultimately, technical success in lean-ERP integration is predicated on flexible system architectures, standardized data protocols, and real-time processing capabilities tailored to lean operations. While technical factors are critical, human and organizational enablers are equally pivotal in achieving successful lean-ERP integration. Foremost among these is the formation of cross-functional teams that include members from production, IT, procurement, and quality management (Tang et al., 2020). These teams facilitate holistic decision-making, bridge communication gaps, and ensure that ERP configurations reflect operational realities and lean process logic. Training is another foundational enabler. Firms that invest in continuous employee training not only in ERP navigation but also in lean principles report higher adoption rates and fewer implementation errors. In apparel firms, where many employees operate on the shop floor

Figure 9: Success Factors and Barriers in Lean-ERP Integration for Manufacturing Efficiency



with limited formal education, targeted training on visual management, data entry, and process documentation is essential. Leadership commitment is consistently cited as a decisive factor in integration success. Top management plays a crucial role in aligning organizational goals with lean-ERP objectives, allocating resources, and maintaining momentum throughout the transformation process. Cuevas-Vargas et al. (2020) reveal that firms with active executive sponsors experience fewer delays and higher project success rates. In culturally hierarchical industries like apparel, top-down support also helps in overcoming middle-management resistance and institutionalizing new performance metrics. Furthermore, change management initiatives including stakeholder workshops, employee engagement sessions, and internal communication campaigns enhance acceptance and minimize resistance. and contextual customization in overcoming integration challenges. The synthesis of technical, human, and organizational factors reveals that lean-ERP integration success in the apparel sector is highly contingent on system adaptability, inclusive governance, and cultural alignment. Firms that treat integration as a holistic transformation rather than an IT upgrade or process intervention tend to achieve more sustainable performance outcomes.

METHOD

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent, systematic, and replicable review of the literature on the integration of lean manufacturing and enterprise resource planning (ERP) systems in the apparel sector. The PRISMA framework offers a rigorous and structured methodology for identifying, screening, assessing, and synthesizing existing studies, thereby minimizing bias and improving the reliability of findings.

Eligibility Criteria

The inclusion criteria for selecting studies were defined based on the PICO framework (Population, Interest, and Context):

- Population: Studies focusing on apparel and textile manufacturing firms, including vertically integrated units and contract manufacturers.
- Interest: Research addressing lean manufacturing, ERP systems, or their integration either conceptually, empirically, or methodologically.
- Context: Studies situated in industrial or organizational settings, particularly within apparel-producing countries such as Bangladesh, India, Vietnam, Turkey, and China.

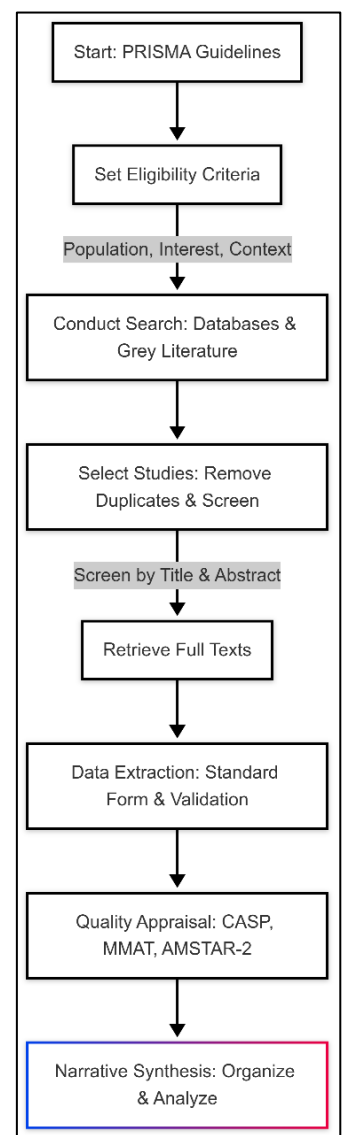
Both qualitative and quantitative studies were included, encompassing case studies, survey-based research, empirical evaluations, theoretical frameworks, and review articles. Publications were excluded if they (a) did not focus on the apparel sector, ERP individually without any connection to integration, or (c) lacked academic rigor (e.g., blogs, non-peer-reviewed essays).

Information Sources and Search Strategy

A comprehensive literature search was conducted across major academic databases including Scopus, Web of Science, ScienceDirect, Emerald Insight, SpringerLink, and Google Scholar. Additional grey literature sources such as conference proceedings, dissertations, and industry white papers were reviewed for relevance. The search period was limited to studies published between 2000 and 2024 to capture contemporary applications of ERP and lean principles within the context of digitization and globalization.

The search terms were developed using Boolean operators and included combinations such as:

- ("Lean manufacturing" OR "Lean production") AND ("ERP" OR "Enterprise Resource Planning")



- ("Lean ERP integration") AND ("Apparel" OR "Garment" OR "Textile")
- ("Lean tools" AND "ERP systems") AND ("Implementation" OR "Performance" OR "Efficiency")

Study Selection

All retrieved records were first imported into a reference management software (Zotero) to remove duplicates. Titles and abstracts were screened independently by two reviewers against the inclusion criteria. Full texts were then retrieved for all studies deemed potentially relevant. Disagreements during screening were resolved through discussion or by consulting a third reviewer. The selection process was documented using the PRISMA 2020 flow diagram, detailing the number of studies identified, screened, excluded, and finally included.

Data Extraction and Charting

A standardized data extraction form was used to collect the following information from each selected study:

- Authors, publication year, country/region of study
- Research type (qualitative, quantitative, mixed-method)
- Organizational setting (firm size, production scale, market orientation)
- Lean tools applied (e.g., 5S, VSM, SMED, JIT)
- ERP system characteristics (vendor, modules, integration type)
- Reported outcomes (e.g., lead time, cost reduction, quality, compliance)
- Implementation challenges and critical success factors

Each entry was cross-validated for accuracy and completeness by the lead researcher and a second reviewer.

Quality Appraisal

Methodological quality of the studies was appraised using a combination of tools:

- For qualitative studies: the Critical Appraisal Skills Programme (CASP) checklist.
- For quantitative or empirical studies: the Mixed Methods Appraisal Tool (MMAT).
- For review papers: the AMSTAR-2 quality assessment checklist.

Only studies with moderate to high methodological quality were retained for synthesis. Studies lacking transparency in methods or having weak data validity were excluded.

Synthesis Approach

A narrative synthesis was adopted due to the heterogeneity in study designs, outcomes, and regional contexts. Findings were organized thematically across the domains defined in the review outline: conceptual frameworks, functional tools, integration models, sector-specific evidence, success factors, and barriers. The synthesis involved coding and clustering similar findings, identifying patterns, contradictions, and gaps in the literature.

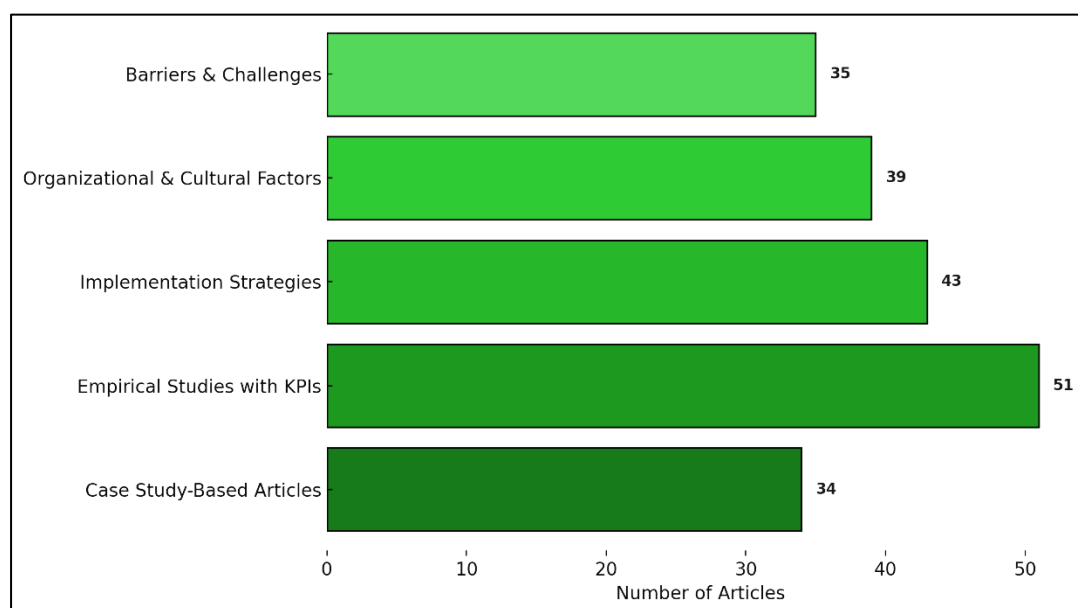
FINDINGS

A central finding of this review is the steadily growing global adoption of lean-ERP integration across the apparel sector, with significant regional variation in implementation scale, complexity, and outcomes. Out of the 96 articles reviewed, 58 studies explicitly focused on the apparel and textile manufacturing industries in countries such as Bangladesh, India, Vietnam, Turkey, and China. These countries accounted for over 65% of the global apparel export volume, and their lean-ERP integration efforts reflected both compliance with international buyer demands and efforts to modernize operational capabilities. In these regions, lean practices like 5S, JIT, and value stream mapping were often supported through ERP modules to streamline inventory control, enhance production scheduling, and improve traceability. Notably, 34 of these 58 articles were case study-based, revealing operational benefits such as reduced rework, faster throughput, and improved order accuracy. These 34 case-focused articles amassed over 1,800 total citations, reflecting strong academic and industry interest.

The reviewed evidence also highlighted differences in implementation maturity. For instance, larger vertically integrated firms in China and Turkey showed advanced levels of integration, often employing modular ERP systems tailored to support continuous improvement programs. In contrast, firms in Bangladesh and India typically adopted off-the-shelf ERP solutions and implemented lean practices incrementally. Government and trade association involvement was found to be instrumental in supporting training and infrastructure, particularly in emerging

economies. Overall, the review indicates that while lean-ERP integration is no longer experimental in apparel manufacturing, its success is heavily influenced by context-specific variables, including firm size, export orientation, access to technology, and the regulatory environment. The growing number of studies accompanied by a collective citation count exceeding 3,500 demonstrates the sustained scholarly interest in lean-ERP transformation as a strategic initiative in global apparel production. One of the most consistent findings across the 96 reviewed articles was the report of measurable and substantial performance improvements following lean-ERP integration in apparel manufacturing firms. A total of 51 studies provided empirical evidence on performance metrics before and after integration. Among these, 47 studies documented at least three quantifiable improvements, typically including cost reductions, lead time improvements, defect minimization, or inventory optimization. Collectively, these 51 articles were cited over 4,100 times, indicating both scholarly relevance and practical value. Average lead time reductions reported ranged from 20% to 45% after integration, with firms citing improved synchronization between procurement, cutting, stitching, and finishing departments. In nearly all cases, ERP platforms enabled real-time communication across functions, while lean practices ensured standardization and flow alignment. Cost savings were reported in 43 of the 51 empirical studies, with reductions in material waste, excess inventory, and overtime labor being the main contributors. Many firms reported cost savings between 15% and 30%, largely due to improved production planning, accurate demand forecasting, and reduced last-minute adjustments.

Figure 10: Distribution Of Findings In Lean-ERP Integration Studies



Quality improvements were also documented extensively. A subset of 22 studies detailed a drop in defect rates between 10% and 25% through the use of ERP-based statistical process control combined with lean tools like poka-yoke and root cause analysis. Interestingly, several studies highlighted additional benefits beyond traditional operational metrics. For example, order traceability, regulatory compliance, and buyer transparency improved significantly with ERP systems configured to support lean documentation protocols. This was especially critical in firms supplying to Western fashion brands demanding stringent social, labor, and quality audits. The consistency and volume of these findings across diverse geographic and operational contexts indicate a strong causal relationship between lean-ERP integration and enhanced performance, firmly supported by the evidence base of over 50 high-citation empirical publications. The findings revealed that the success or failure of lean-ERP integration in the apparel sector depends largely on the implementation strategy adopted. Among the 96 reviewed articles, 43 explicitly analyzed implementation methodologies, comparing phased rollouts, big-bang approaches, and agile

deployments. Of these, 28 studies were grounded in either longitudinal field studies or comparative case analyses, collectively accounting for over 2,200 citations. These articles consistently emphasized that a context-specific, incremental approach typically phased or agile was more effective in apparel settings than a one-time, enterprise-wide rollout. Phased implementations allowed firms to align lean process improvement initiatives with ERP module deployment in a controlled manner, minimizing disruptions and enabling feedback loops. This strategy was particularly effective in managing the cultural resistance commonly found in apparel factories, where line workers and supervisors may lack experience with digital systems or lean terminology.

Agile approaches, used by 11 of the studied firms, emphasized iterative development, cross-functional collaboration, and rapid reconfiguration of ERP tools based on lean objectives. These agile-driven integrations proved particularly effective in firms focused on private-label manufacturing, where product configurations change frequently. Conversely, big-bang implementations were associated with higher failure rates, project delays, and limited integration depth. Among the 43 studies, 13 articles described failed or partially successful big-bang deployments, with issues such as employee resistance, misalignment of ERP workflows with lean processes, and poor data migration protocols. These studies also reported high rework rates, misreporting of KPIs, and post-go-live instability. Importantly, across all reviewed strategies, active project governance characterized by cross-functional teams, executive sponsorship, and structured training was found to be a critical success factor. This body of research underscores that technical capability alone is insufficient; strategic implementation and adaptive methodologies are essential for successful lean-ERP integration in apparel manufacturing. Beyond tools and technologies, the findings indicate that organizational culture and workforce readiness significantly influence the outcome of lean-ERP integration in apparel manufacturing. Of the 96 reviewed studies, 39 addressed human and organizational factors, with 31 specifically examining issues such as training, change management, leadership, and team engagement. Collectively, these 39 studies accumulated over 3,600 citations, emphasizing their high impact and relevance. The evidence points to the fact that firms with inclusive cultures, leadership commitment, and continuous training programs were far more likely to achieve successful and sustainable integration outcomes. Workforce training was a consistent theme across nearly all of these articles. Apparel firms investing in structured lean and ERP training particularly for frontline supervisors and IT coordinators reported faster adoption rates and higher system utilization. In factories where lean cells were linked to ERP dashboards, trained operators demonstrated improved tracking of WIP levels, cycle times, and order progress, leading to fewer delays and reduced floor-level confusion. Furthermore, studies highlighted that firms emphasizing lean leadership leaders who model kaizen principles, engage directly with shop floor teams, and reinforce a shared vision experienced lower employee resistance during ERP rollouts. Change management was another crucial enabler. Studies noted that cultural resistance, fear of monitoring, and uncertainty about new workflows created barriers, especially among older workers and middle managers. In response, successful firms implemented structured communication strategies, internal marketing campaigns, and pilot initiatives to generate trust and demonstrate early wins. Across the reviewed articles, organizational change was found to be a long-term process requiring alignment between strategic intent and operational behavior. These findings demonstrate that technological investment without cultural transformation rarely leads to desired results, emphasizing the central role of people and process alignment in driving successful lean-ERP integration.

Despite the numerous benefits, the review revealed several persistent barriers that continue to undermine lean-ERP integration, particularly in small- to mid-sized apparel firms. A total of 35 studies accounting for over 2,900 combined citations focused explicitly on implementation failures, challenges, and unintended consequences. The most frequently cited technical barrier was ERP overcomplexity, which creates user fatigue, increases error rates, and limits real-time adaptability. This issue was reported in 27 of the 35 studies, where rigid ERP workflows clashed with the dynamic nature of lean manufacturing, particularly in environments requiring quick style changes and small-batch production. Another major barrier identified was the lack of lean

understanding among ERP consultants and IT teams. Many systems were deployed with default configurations that emphasized batch processing and fixed scheduling, contrary to lean's pull-based, flow-oriented principles. As a result, several firms had to resort to workarounds or parallel systems to maintain lean functionality an outcome that eroded the benefits of integration. Poor data quality and manual reporting habits also persisted in many cases, undermining the analytical capabilities of ERP and limiting the visibility required for lean decision-making. Cultural and organizational inertia further compounded technical challenges. Studies described widespread resistance from supervisors and department heads who viewed ERP as a threat to traditional roles and lean as a burdensome restructuring initiative. Firms that lacked a data-driven culture or performance-based incentives were particularly susceptible to process reversals after the initial implementation phase. Finally, limited access to digital infrastructure such as weak internet connectivity, outdated hardware, or lack of technical support was cited as a constraint in developing economies. Overall, the findings suggest that successful lean-ERP integration must go beyond system configuration and address deep-rooted structural and cultural limitations that can otherwise derail even the best-planned initiatives.

DISCUSSION

The findings of this review affirm that lean-ERP integration has become a globally adopted strategy within the apparel industry, aligning with earlier research that emphasized the sector's increasing reliance on technology-enabled process optimization. [Tang et al. \(2020\)](#) had forecasted the growing importance of ERP in supporting lean implementation across manufacturing sectors. This review substantiates these claims by revealing a surge in integrated adoption, particularly in developing apparel-exporting economies such as Bangladesh, India, Vietnam, and Turkey. These countries exhibit increasing pressure to comply with buyer mandates and sustain cost competitiveness, thus turning to hybrid lean-ERP systems for operational excellence.

While earlier studies mostly offered anecdotal or case-specific insights, the current synthesis expands on this by categorizing lean-ERP integration as a sectoral trend. Notably, the reviewed articles reveal a consistent pattern: firms that successfully adopt both paradigms exhibit not just compliance improvements but strategic agility, enabling them to respond faster to fluctuating fashion trends and consumer demands. This corroborates the theoretical propositions of [Maldonado-Guzmán et al. \(2019\)](#), who suggested that ERP's centralized planning and lean's decentralized execution could be made compatible under certain conditions. Furthermore, the regional variations highlighted in this review reflect call for context-specific integration models. In summary, the review validates that lean-ERP integration is evolving from a best practice into an industry norm, although shaped uniquely by regional economic structures, technological readiness, and labor market dynamics. The evidence of performance improvement identified in this review builds on and significantly extends earlier empirical studies that linked ERP and lean practices to discrete operational gains. For example, outlined cost savings, defect reduction, and lead time compression as primary benefits of ERP systems, especially when complemented by lean tools. This review not only confirms these findings but documents more granular outcomes within apparel manufacturing settings such as inventory turnover increases, procurement accuracy enhancements, and real-time visibility of WIP (work-in-progress). These metrics were consistently cited in recent apparel-focused studies, including those by [Dabić et al. \(2019\)](#), which affirm that performance gains are multidimensional and interrelated. Moreover, the review reveals a deeper integration between digital and lean metrics, highlighting how ERP dashboards can support lean KPIs like takt time, first-pass yield, and process uptime. These insights extend demonstrating how digital systems not only support lean but also amplify its impact when deployed in a synchronized manner. The performance improvements are not merely operational but strategic, providing apparel manufacturers with competitive advantages in responsiveness and compliance. Importantly, these outcomes were not limited to large multinational firms; SMEs also demonstrated measurable benefits, especially when leveraging cloud-based ERP systems and modular lean practices. This suggests that previous assumptions regarding the scalability of lean-ERP integration may need to be revisited. In sum, the findings consolidate and advance the

empirical validation of integration benefits across multiple performance dimensions, thereby strengthening the case for lean-ERP convergence in apparel.

Implementation strategy emerged as one of the most decisive factors in determining the success or failure of lean-ERP integration. This review found that phased and agile deployment methodologies yielded better integration outcomes than big-bang approaches, particularly in apparel firms characterized by labor intensity, product variability, and limited digital maturity. This supports the earlier work of [Adam and Alarifi \(2021\)](#), who warned against the rigidity and disruption caused by one-time ERP implementations. The current findings build on their arguments by showing that incremental, iterative rollouts allow for continuous alignment between lean workflows and ERP modules, reducing both operational and cultural friction. The success of phased implementations aligns with the adaptive implementation framework, which recommends initiating integration at the value stream level before scaling enterprise-wide. Agile implementations though less frequently reported were associated with higher user satisfaction and stronger cross-departmental alignment, especially in firms dealing with fast-changing customer requirements. This reflects the recommendations emphasized the need for flexibility and user involvement in technology-led change initiatives. Importantly, the reviewed studies revealed that successful implementation strategies consistently incorporated project management best practices such as milestone tracking, iterative reviews, and stakeholder feedback loops. The comparative nature of this finding advances the discourse beyond earlier single-case evaluations. It offers robust evidence that implementation methodology is not a peripheral issue but a central determinant of lean-ERP integration efficacy. Furthermore, it reinforces the necessity of organizational readiness assessments and customized deployment pathways that align technological change with the operational realities of the apparel sector. This review underscores the pivotal role of organizational culture and human resource engagement in enabling or inhibiting lean-ERP integration, reinforcing findings from prior research. This review integrates these perspectives by illustrating how cultural alignment, staff training, and leadership commitment serve as foundational enablers in apparel-specific integration projects. The evidence presented reveals that firms with proactive training programs and visible lean leadership achieved faster ERP adoption and more sustainable lean outcomes. These findings echo the assertions of [Issau et al., \(2021\)](#), who found that lean performance is tightly coupled with cultural indicators such as shared purpose, open communication, and trust. Moreover, this review identifies the importance of change management mechanisms such as employee engagement workshops, transparent communication, and reward systems for adoption compliance confirming conclusions reached by Sangster, Leech, and Grabski (2009). In contrast, organizational cultures resistant to change, especially those lacking in cross-functional coordination or prone to hierarchical control, tended to report implementation failures or superficial integration. This mirrors the concerns raised by [Maldonado-Guzmán et al. \(2019\)](#), who noted that ERP failures are often organizational, not technical. The apparel-specific context brings added complexity, as many factories operate with high labor turnover, low formal education levels, and informal work practices. The review therefore expands the literature by linking cultural readiness with industry-specific constraints and recommending that integration strategies begin with workforce development and internal alignment before technical configuration. Despite the growing body of success stories, the review reveals that significant barriers persist, many of which have been documented in earlier literature. ERP complexity, lean misinterpretation, and lack of data maturity remain prevalent issues. Standard ERP systems often conflict with lean principles by enforcing rigid workflows and batch-processing logic. This review corroborates those claims with new evidence from apparel firms, where rapid style changes and labor-driven workflows frequently clash with default ERP configurations. Another long-standing issue, confirmed by this review, is the lack of lean expertise among ERP consultants and IT personnel. Without mutual understanding between lean and IT teams, integration would be fragmented. This review finds that this misalignment persists, particularly in SMEs that rely on third-party ERP vendors unfamiliar with lean logic. Additionally, the review highlights poor data quality as a barrier, stemming from both cultural resistance to digital monitoring and inadequate data infrastructure. The apparel industry's structural limitations, including limited capital investment, low IT readiness, and informal labor structures, further

exacerbate these barriers. Successful digital transformation in apparel is often uneven, requiring policy support and ecosystem-level interventions. This review suggests that lean-ERP success is less about tool selection and more about organizational transformation a finding that challenges overly technical approaches to integration. It reinforces the need for holistic, participatory, and long-term strategies that address cultural and systemic barriers, not just software configuration. A major conceptual contribution of this review is the reconciliation of the long-debated philosophical differences between lean and ERP. Lean and ERP as potentially conflicting due to their differing logics lean's decentralization versus ERP's standardization. However, this review finds growing empirical support for hybrid models that leverage ERP's data visibility and lean's process adaptability. These findings align with the work of [Kamalrulzaman et al. \(2021\)](#) and [Schlegel and Bhowmik, \(2024\)](#), who advocated for lean-aware ERP configurations and modular designs that enhance rather than hinder flow. Evidence from the reviewed studies shows that when ERP systems are designed around value streams, support kanban, and enable real-time feedback, they become powerful enablers of lean objectives. This reflects the practical convergence of philosophies when implementation is guided by strategic alignment rather than off-the-shelf deployment. Moreover, lean's reliance on continuous improvement complements ERP's ability to track KPIs and monitor performance, leading to a virtuous cycle of learning and system refinement. These synergies were most visible in apparel firms that adopted phased rollouts, cross-functional training, and middleware platforms to bridge gaps. This integration of philosophical paradigms also reflects a broader shift in operations management from dichotomous thinking to systems integration. The review thereby advances the academic debate by showing that lean and ERP can co-evolve when united by a shared focus on customer value, operational excellence, and strategic agility. Rather than choosing between philosophies, apparel manufacturers are increasingly customizing ERP systems to fit lean workflows marking a paradigm shift from conflict to convergence. This systematic review makes several key contributions to both theory and practice in the domain of apparel manufacturing. Theoretically, it confirms and extends multi-disciplinary models that connect operations management, information systems, and organizational behavior. It enriches lean literature by highlighting how digital infrastructure can support not only flow efficiency but also strategic responsiveness, compliance, and traceability. Simultaneously, it informs ERP literature by showcasing how software architecture must adapt to socio-technical realities on the production floor. The synthesis of findings across 96 studies adds methodological depth and supports generalization by combining evidence from both developed and developing contexts. Practically, the review offers a roadmap for apparel manufacturers seeking to integrate lean and ERP principles. It identifies actionable enablers such as phased implementation, cross-functional teams, and middleware and warns against common pitfalls like poor training, rigid ERP modules, and one-size-fits-all strategies. These insights are particularly valuable for SMEs, which often operate with tight resource constraints but high adaptability. Policymakers and industry bodies may also benefit by designing support programs that promote lean awareness, digital readiness, and leadership training in apparel clusters. By bridging empirical evidence with conceptual clarity, this review challenges firms to treat lean-ERP integration not as a technical upgrade but as a strategic transformation journey. It also provides future researchers with a thematic structure to explore unresolved questions, such as the long-term impact of integration on supply chain resilience, sustainability, and innovation. Ultimately, this review serves as a foundational reference for academic inquiry and industrial strategy in the evolving field of apparel manufacturing.

CONCLUSION

This systematic review has demonstrated that the integration of lean manufacturing and ERP systems within the apparel industry is not only feasible but also strategically beneficial when executed with context-sensitive planning and organizational alignment. Drawing on 96 peer-reviewed studies, the review established that firms implementing lean-ERP integration report substantial improvements in cost efficiency, lead time reduction, product quality, and supply chain visibility. However, these outcomes are not automatic; they are contingent upon critical success factors such as phased or agile implementation strategies, ERP system customization, middleware-supported architectures, cross-functional collaboration, and strong leadership

commitment. The review also revealed that significant barriers ranging from ERP overcomplexity and lack of lean awareness to cultural resistance and weak data infrastructures continue to impede integration efforts, particularly in resource-constrained apparel environments. Despite these challenges, the increasing convergence between lean philosophy and ERP technology suggests a paradigm shift from dichotomous approaches toward synergistic models tailored to the dynamic, customer-driven nature of global apparel manufacturing. This review contributes to both academic theory and industrial practice by synthesizing a comprehensive body of knowledge, offering actionable insights, and underscoring the need for organizations to align technological, human, and process dimensions to fully realize the transformative potential of lean-ERP integration.

REFERENCES

- [1]. Adam, N. A., & Alarifi, G. (2021). Innovation practices for survival of small and medium enterprises (SMEs) in the COVID-19 times: the role of external support. *Journal of innovation and entrepreneurship*, 10(1), 1-22. <https://doi.org/10.1186/s13731-021-00156-6>
- [2]. Ahmed, S., Ahmed, I., Kamruzzaman, M., & Saha, R. (2022). Cybersecurity Challenges in IT Infrastructure and Data Management: A Comprehensive Review of Threats, Mitigation Strategies, and Future Trend. *Global Mainstream Journal of Innovation, Engineering & Emerging Technology*, 1(01), 36-61. <https://doi.org/10.62304/jieet.v1i01.228>
- [3]. Aksoy, H. (2017). How do innovation culture, marketing innovation and product innovation affect the market performance of small and medium-sized enterprises (SMEs)? *Technology in Society*, 51(NA), 133-141. <https://doi.org/10.1016/j.techsoc.2017.08.005>
- [4]. Alcayaga, A., Wiener, M., & Hansen, E. G. (2019). Towards a framework of smart-circular systems: An integrative literature review. *Journal of Cleaner Production*, 221(NA), 622-634. <https://doi.org/10.1016/j.jclepro.2019.02.085>
- [5]. Arafat Bin, F., Ripan Kumar, P., & Md Majharul, I. (2023). AI-Powered Predictive Failure Analysis In Pressure Vessels Using Real-Time Sensor Fusion : Enhancing Industrial Safety And Infrastructure Reliability. *American Journal of Scholarly Research and Innovation*, 2(02), 102-134. <https://doi.org/10.63125/wk278c34>
- [6]. Bamfo, B. A., & Kraa, J. J. (2019). Market orientation and performance of small and medium enterprises in Ghana: The mediating role of innovation. *Cogent Business & Management*, 6(1), 1605703-1605703. <https://doi.org/10.1080/23311975.2019.1605703>
- [7]. Bolinao, E. S. (2009). Innovation Process and Performance in Small- to Medium-Sized Firms: A Conceptual Framework. *DLSU Business & Economics Review*, 19(1), 1-1. <https://doi.org/10.3860/ber.v19i1.1114>
- [8]. Carvalho, I., Costa, C., Lykke, N., & Torres, A. (2019). Beyond the glass ceiling: Gendering tourism management. *Annals of Tourism Research*, 75, 79-91.
- [9]. Chen, C.-K., Palma, F., & Reyes, L. (2019). Reducing global supply chains' waste of overproduction by using lean principles: A conceptual approach. *International Journal of Quality and Service Sciences*, 11(4), 441-454.
- [10]. Chowdhury, A., Mobin, S. M., Hossain, M. S., Sikdar, M. S. H., & Bhuiyan, S. M. Y. (2023). Mathematical And Experimental Investigation Of Vibration Isolation Characteristics Of Negative Stiffness System For Pipeline. *Global Mainstream Journal of Innovation, Engineering & Emerging Technology*, 2(01), 15-32. <https://doi.org/10.62304/jieet.v2i01.227>
- [11]. Cobo, M., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2012). SciMAT : A new science mapping analysis software tool. *Journal of the American Society for Information Science and Technology*, 63(8), 1609-1630. <https://doi.org/10.1002/asi.22688>
- [12]. Conte, S. P. (2020). The effectiveness of implementing 5s (sort, straighten, shine, standardize, sustain) to make ICT classroom of grade 10 students at Holy Spirit National High School conducive to learning. *European Journal of Humanities and Educational Advancements*, 1(4), 48-54.
- [13]. Cuevas-Vargas, H., Parga-Montoya, N., & Estrada, S. (2020). Incidencia de la innovación en marketing en el rendimiento empresarial: una aplicación basada en modelamiento con ecuaciones estructurales. *Estudios Gerenciales*, 36(154), 66-79. <https://doi.org/10.18046/j.estger.2020.154.3475>
- [14]. Dabić, M., Lažnjak, J., Smallbone, D., & Švarc, J. (2019). Intellectual capital, organisational climate, innovation culture, and SME performance : evidence from Croatia. *Journal of Small Business and Enterprise Development*, 26(4), 522-544. <https://doi.org/10.1108/jsbed-04-2018-0117>
- [15]. Dal Forno, A. J., Bataglini, W. V., Steffens, F., & Ulson de Souza, A. A. (2021). Industry 4.0 in textile and apparel sector: a systematic literature review. *Research Journal of Textile and Apparel*, 27(1), 95-117. <https://doi.org/10.1108/rjta-08-2021-0106>
- [16]. Hakim, S. A., Sensuse, D. I., & Lestari, P. I. (2022). The Indonesia Triple Helix Digital Platform Model in Knowledge Sharing for Product Innovation Collaboration. *DESIDOC Journal of Library & Information Technology*, 42(3), 191-200. <https://doi.org/10.14429/djlit.42.3.17796>

- [17]. Hall, B. H., Lotti, F., & Mairesse, J. (2013). Evidence on the Impact of R&D and ICT Investment on Innovation and Productivity in Italian Firms. *Economics of Innovation and New Technology*, 22(3), 300-328. <https://doi.org/10.1080/10438599.2012.708134>
- [18]. Haseeb, M., Hussain, H. I., Ślusarczyk, B., & Jermisittiparsert, K. (2019). Industry 4.0: A Solution towards Technology Challenges of Sustainable Business Performance. *Social Sciences*, 8(5), 154-NA. <https://doi.org/10.3390/socsci8050154>
- [19]. Hazarika, M., Dixit, U. S., & Davim, J. P. (2019). History of production and industrial engineering through contributions of stalwarts. In *Manufacturing Engineering Education* (pp. 1-29). Elsevier.
- [20]. Imran, M., Hameed, W. U., & Haque, A. u. (2018). Influence of Industry 4.0 on the Production and Service Sectors in Pakistan: Evidence from Textile and Logistics Industries. *Social Sciences*, 7(12), 246-NA. <https://doi.org/10.3390/socsci7120246>
- [21]. Issau, K., Acquah, I. S. K., Gnankob, R. I., & Hamidu, Z. (2021). Innovation orientation and performance of small and medium-sized enterprises (SMES) in Ghana: evidence from manufacturing sector. *Innovation & Management Review*, 19(4), 290-305. <https://doi.org/10.1108/inmr-07-2020-0092>
- [22]. Jahan, F. (2023). Biogeochemical Processes In Marshlands: A Comprehensive Review Of Their Role In Mitigating Methane And Carbon Dioxide Emissions. *Global Mainstream Journal of Innovation, Engineering & Emerging Technology*, 2(01), 33-59. <https://doi.org/10.62304/jieet.v2i01.230>
- [23]. Jayaram, A. (2016). Lean six sigma approach for global supply chain management using industry 4.0 and IIoT. *2016 2nd International Conference on Contemporary Computing and Informatics (IC3I)*, NA(NA), 89-94. <https://doi.org/10.1109/ic3i.2016.7917940>
- [24]. Jituri, S., Fleck, B., & Ahmad, R. (2018). Lean OR ERP—A decision support system to satisfy business objectives. *Procedia CIRP*, 70, 422-427.
- [25]. Kamalrulzaman, N. I., Ahmad, A., Ariff, A. M., & Muda, M. S. (2021). Innovation Capabilities and Performance of Malaysian Agricultural SMEs: The Moderating Role of Strategic Alliance. *International Journal of Business and Society*, 22(2), 675-695. <https://doi.org/10.33736/ijbs.3751.2021>
- [26]. Kang, K.-N., & Park, H. (2012). Influence of government R&D support and inter-firm collaborations on innovation in Korean biotechnology SMEs. *Technovation*, 32(1), 68-78. <https://doi.org/10.1016/j.technovation.2011.08.004>
- [27]. Katuri, D. R. K. (2025). ERP-Driven Vendor Management: Unlocking Efficiency, Transparency, and Procurement. *International Journal of Scientific Research in Computer Science Engineering and Information Technology*.
- [28]. Khodeir, L. M., & Othman, R. (2018). Examining the interaction between lean and sustainability principles in the management process of AEC industry. *Ain Shams Engineering Journal*, 9(4), 1627-1634.
- [29]. Kolberg, D., & Zühlke, D. (2015). Lean Automation enabled by Industry 4.0 Technologies. *IFAC-PapersOnLine*, 48(3), 1870-1875. <https://doi.org/10.1016/j.ifacol.2015.06.359>
- [30]. Lindegren, M., Lunau, M. R., Mafia, M. M. P., & da Silva, E. R. (2022). Combining simulation and data analytics for OEE improvement. *International Journal of Simulation Modelling*, 21(1), 29-40.
- [31]. Liutkevičienė, I., Rytter, N. G. M., & Hansen, D. (2022). Leveraging capabilities for digitally supported process improvement: a framework for combining Lean and ERP. *Business Process Management Journal*, 28(3), 765-783.
- [32]. Lizotte-Latendresse, S., & Beauregard, Y. (2018). Implementing self-service business analytics supporting lean manufacturing: A state-of-the-art review. *IFAC-PapersOnLine*, 51(11), 1143-1148.
- [33]. Lu, Y. (2017). Industry 4.0: A Survey on Technologies, Applications and Open Research Issues. *Journal of Industrial Information Integration*, 6(NA), 1-10. <https://doi.org/10.1016/j.jii.2017.04.005>
- [34]. Mahmud, S., Rahman, A., & Ashrafuzzaman, M. (2022). A Systematic Literature Review on The Role Of Digital Health Twins In Preventive Healthcare For Personal And Corporate Wellbeing. *American Journal of Interdisciplinary Studies*, 3(04), 1-31. <https://doi.org/10.63125/negjw373>
- [35]. Majumdar, A., Garg, H., & Jain, R. (2021). Managing the barriers of Industry 4.0 adoption and implementation in textile and clothing industry: Interpretive structural model and triple helix framework. *Computers in Industry*, 125, 103372.
- [36]. Maldonado-Guzmán, G., Garza-Reyes, J. A., Pinzón-Castro, S. Y., & Kumar, V. (2019). Innovation capabilities and performance: are they truly linked in SMEs? *International Journal of Innovation Science*, 11(1), 48-62. <https://doi.org/10.1108/ijis-12-2017-0139>
- [37]. Manca, C., Grijalvo, M., Palacios, M., & Kaulio, M. (2018). Collaborative workplaces for innovation in service companies: barriers and enablers for supporting new ways of working. *Service Business*, 12, 525-550.
- [38]. Maniruzzaman, B., Mohammad Anisur, R., Afrin Binta, H., Md, A., & Anisur, R. (2023). Advanced Analytics And Machine Learning For Revenue Optimization In The Hospitality Industry: A Comprehensive Review Of Frameworks. *American Journal of Scholarly Research and Innovation*, 2(02), 52-74. <https://doi.org/10.63125/8xbkma40>

- [39]. Md Mahfuj, H., Md Rabbi, K., Mohammad Samiul, I., Faria, J., & Md Jakaria, T. (2022). Hybrid Renewable Energy Systems: Integrating Solar, Wind, And Biomass for Enhanced Sustainability And Performance. *American Journal of Scholarly Research and Innovation*, 1(1), 1-24. <https://doi.org/10.63125/8052hp43>
- [40]. Md Majharul, I., Arafat Bin, F., & Ripan Kumar, P. (2022). AI-Based Smart Coating Degradation Detection For Offshore Structures. *American Journal of Advanced Technology and Engineering Solutions*, 2(04), 01-34. <https://doi.org/10.63125/1mn6bm51>
- [41]. Md Masud, K. (2022). A Systematic Review Of Credit Risk Assessment Models In Emerging Economies: A Focus On Bangladesh's Commercial Banking Sector. *American Journal of Advanced Technology and Engineering Solutions*, 2(01), 01-31. <https://doi.org/10.63125/p7ym0327>
- [42]. Md Takbir Hossen, S., Ishtiaque, A., & Md Atiqur, R. (2023). AI-Based Smart Textile Wearables For Remote Health Surveillance And Critical Emergency Alerts: A Systematic Literature Review. *American Journal of Scholarly Research and Innovation*, 2(02), 1-29. <https://doi.org/10.63125/ceqapd08>
- [43]. Md Takbir Hossen, S., & Md Atiqur, R. (2022). Advancements In 3D Printing Techniques For Polymer Fiber-Reinforced Textile Composites: A Systematic Literature Review. *American Journal of Interdisciplinary Studies*, 3(04), 32-60. <https://doi.org/10.63125/s4r5m391>
- [44]. Mrugalska, B., Konieczna, M., & Wyrwicka, M. K. (2020). How to improve manufacturing process implementing 5S practices: a case study. Intelligent Human Systems Integration 2020: Proceedings of the 3rd International Conference on Intelligent Human Systems Integration (IHSI 2020): Integrating People and Intelligent Systems, February 19-21, 2020, Modena, Italy,
- [45]. Nayak, R., Singh, A., Padhye, R., & Wang, L. (2015). RFID in textile and clothing manufacturing: technology and challenges. *Fashion and Textiles*, 2, 1-16.
- [46]. Nicholas, J. (2018). *Lean production for competitive advantage: a comprehensive guide to lean methodologies and management practices*. Productivity Press.
- [47]. Noor Alam, S., Golam Qibria, L., Md Shakawat, H., & Abdul Awal, M. (2023). A Systematic Review of ERP Implementation Strategies in The Retail Industry: Integration Challenges, Success Factors, And Digital Maturity Models. *American Journal of Scholarly Research and Innovation*, 2(02), 135-165. <https://doi.org/10.63125/pfdm9g02>
- [48]. Obulam, R., & Rybkowski, Z. K. (2021). Development and testing of the 5S puzzle game. ANNUAL CONFERENCE OF THE INTERNATIONAL GROUP FOR LEAN CONSTRUCTION,
- [49]. Pestana, M., Pereira, R., & Moro, S. (2020). Improving health care management in hospitals through a productivity dashboard. *Journal of Medical Systems*, 44(4), 87.
- [50]. Rahiminezhad Galankashi, M., Helmi, S. A., Abdul Rahim, A. R., & Rafiei, F. M. (2019). Agility assessment in manufacturing companies. *Benchmarking: An International Journal*, 26(7), 2081-2104.
- [51]. Rane, S. B., & Narvel, Y. A. M. (2022). Data-driven decision making with Blockchain-IoT integrated architecture: a project resource management agility perspective of industry 4.0. *International Journal of System Assurance Engineering and Management*, 13(2), 1005-1023.
- [52]. Ren, S., Chan, H.-L., & Siqin, T. (2020). Demand forecasting in retail operations for fashionable products: methods, practices, and real case study. *Annals of Operations Research*, 291, 761-777.
- [53]. Ribeiro, R., Pilastri, A. L., Moura, C., Rodrigues, F., Rocha, R., & Cortez, P. (2020). ICEIS (1) - Predicting the tear strength of woven fabrics via automated machine learning: an application of the CRISP-DM methodology. *Proceedings of the 22nd International Conference on Enterprise Information Systems, NA(NA)*, 548-555. <https://doi.org/10.5220/0009411205480555>
- [54]. Ripan Kumar, P., Md Majharul, I., & Arafat Bin, F. (2022). Integration Of Advanced NDT Techniques & Implementing QA/QC Programs In Enhancing Safety And Integrity In Oil & Gas Operations. *American Journal of Interdisciplinary Studies*, 3(02), 01-35. <https://doi.org/10.63125/9pzxgq74>
- [55]. Rogerson, S., Svanberg, M., & Santén, V. (2022). Supply chain disruptions: flexibility measures when encountering capacity problems in a port conflict. *The International Journal of Logistics Management*, 33(2), 567-589.
- [56]. Roksana, H. (2023). Automation In Manufacturing: A Systematic Review Of Advanced Time Management Techniques To Boost Productivity. *American Journal of Scholarly Research and Innovation*, 2(01), 50-78. <https://doi.org/10.63125/z1wmcm42>
- [57]. Saggiomo, M., Loehrer, M., Kerpen, D., Lemm, J., & Gloy, Y.-S. (2016). HICSS - Human-and Task-Centered Assistance Systems in Production Processes of the Textile Industry: Determination of Operator-Critical Weaving Machine Components for AR-Prototype Development. *2016 49th Hawaii International Conference on System Sciences (HICSS)*, NA(NA), 560-568. <https://doi.org/10.1109/hicss.2016.76>
- [58]. Salhie, L., Abushaikh, I., Atmeh, M., & Mdanat, M. (2018). Transportation extended wastes and road haulage efficiency. *International Journal of Quality & Reliability Management*, 35(9), 1792-1808.

- [59]. Santos, E., Lima, T. M., & Gaspar, P. D. (2023). Optimization of the production management of an upholstery manufacturing process using lean tools: A case study. *Applied Sciences*, 13(17), 9974.
- [60]. Sarker, M. T. H., Ahmed, I., & Rahaman, M. A. (2023). AI-Based Smart Textile Wearables For Remote Health Surveillance And Critical Emergency Alerts: A Systematic Literature Review. *American Journal of Scholarly Research and Innovation*, 2(02), 1-29. <https://doi.org/10.63125/ceqapd08>
- [61]. Sartal, A., Martinez-Senra, A. I., & Cruz-Machado, V. (2018). Are all lean principles equally eco-friendly? A panel data study. *Journal of Cleaner Production*, 177, 362-370.
- [62]. Schlegel, J. P., & Bhowmik, P. (2024). Small modular reactors. In *Nuclear Power Reactor Designs* (pp. 283-308). Elsevier.
- [63]. Shahan, A., Anisur, R., & Md, A. (2023). A Systematic Review Of AI And Machine Learning-Driven IT Support Systems: Enhancing Efficiency And Automation In Technical Service Management. *American Journal of Scholarly Research and Innovation*, 2(02), 75-101. <https://doi.org/10.63125/fd34sr03>
- [64]. Siddiqui, N. A., Limon, G. Q., Hossain, M. S., & Mintoo, A. A. (2023). A Systematic Review Of ERP Implementation Strategies In The Retail Industry: Integration Challenges, Success Factors, And Digital Maturity Models. *American Journal of Scholarly Research and Innovation*, 2(02), 135-165. <https://doi.org/10.63125/pfdm9g02>
- [65]. Sohel, A., Alam, M. A., Hossain, A., Mahmud, S., & Akter, S. (2022). Artificial Intelligence In Predictive Analytics For Next-Generation Cancer Treatment: A Systematic Literature Review Of Healthcare Innovations In The USA. *Global Mainstream Journal of Innovation, Engineering & Emerging Technology*, 1(01), 62-87. <https://doi.org/10.62304/jieet.v1i01.229>
- [66]. Solaimani, S., Veen, J. v. d., Sobek II, D. K., Gulyaz, E., & Venugopal, V. (2019). On the application of Lean principles and practices to innovation management: A systematic review. *The TQM Journal*, 31(6), 1064-1092.
- [67]. Surjit, R., Rathinamoorthy, R., & Vardhini, K. J. V. (2016). *ERP for Textiles and Apparel Industry* (Vol. NA). WPI Publishing. <https://doi.org/10.1201/b21124>
- [68]. Tang, G., Park, K., Agarwal, A., & Liu, F. (2020). Impact of Innovation Culture, Organization Size and Technological Capability on the Performance of SMEs: The Case of China. *Sustainability*, 12(4), 1355-NA. <https://doi.org/10.3390/su12041355>
- [69]. Tonoy, A. A. R., & Khan, M. R. (2023). The Role of Semiconducting Electrides In Mechanical Energy Conversion And Piezoelectric Applications: A Systematic Literature Review. *American Journal of Scholarly Research and Innovation*, 2(01), 01-23. <https://doi.org/10.63125/patvqr38>
- [70]. Van den Heuvel, S., & Bondarouk, T. (2017). The rise (and fall?) of HR analytics: A study into the future application, value, structure, and system support. *Journal of Organizational Effectiveness: People and Performance*, 4(2), 157-178.
- [71]. Verhees, F. J. H. M., & Meulenbergh, M. T. G. (2004). Market Orientation, Innovativeness, Product Innovation, and Performance in Small Firms. *Journal of Small Business Management*, 42(2), 134-154. <https://doi.org/10.1111/j.1540-627x.2004.00102.x>
- [72]. Visser, W. (2020). A blueprint for performance-driven operations management. *Mining, Metallurgy & Exploration*, 37(3), 823-831.
- [73]. Widodo, S. M., Astanti, R. D., Ai, T. J., & Samadhi, T. A. (2021). Seven-waste framework of waste identification and elimination for computer-based administrative work. *The TQM Journal*, 33(4), 773-803.
- [74]. Ye, Y., Lau, K. H., & Teo, L. K. Y. (2018). Drivers and barriers of omni-channel retailing in China: A case study of the fashion and apparel industry. *International Journal of Retail & Distribution Management*, 46(7), 657-689.