International Journal of Scientific Interdisciplinary Research
Vol 1, No 1, December 2022
Page No: 01-26
DOI: 10.63125/dj9fgy65

Article

SUPPLY CHAIN TRACEABILITY IN APPAREL MANUFACTURING: A REVIEW OF REAL-TIME ORDER TRACKING, VENDOR MANAGEMENT, AND EXPORT VISIBILITY SYSTEMS

Golam Qibria Limon[1]

[1] *MBA in Management Information System, International American University, Los Angeles, USA; Email: limonqibria@gmail.com*

Abstract

The complexity and global dispersion of modern apparel supply chains have intensified the need for robust traceability systems that can ensure ethical sourcing, operational efficiency, and regulatory compliance. This study presents an in-depth meta-analysis of traceability mechanisms in apparel manufacturing, focusing specifically on three interconnected dimensions: real-time order tracking, vendor management, and export visibility systems. Drawing upon 113 empirical studies published between 2005 and 2022, the analysis synthesizes technological, organizational, and governance-related approaches to supply chain traceability, with particular attention to digital platforms such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Manufacturing Execution Systems (MES), Transportation Management Systems (TMS), blockchain-enabled infrastructures, and Traceability-as-a-Service (TaaS) models. The findings reveal that while real-time order tracking is well-established at the Tier 1 level through ERP and SCM systems, traceability significantly deteriorates beyond Tier 2 due to subcontracting opacity, fragmented governance, and limited technological integration. Vendor management practices remain largely coercive and audit-driven, which leads to short-term compliance but does not foster sustained transparency or collaborative data sharing. Export visibility tools, while effective in managing container movement and customs documentation, often operate in isolation from broader traceability platforms, resulting in data silos and verification gaps. Furthermore, the study highlights the central role of governance models in shaping traceability outcomes, with collaborative and hybrid approaches demonstrating higher success rates in multi-tier visibility and supplier engagement. It also underscores the growing relevance of blockchain and EDI-based systems in export traceability, emphasizing the benefits and limitations of each. TaaS platforms are identified as emerging enablers of flexible, modular traceability infrastructure, particularly for small and mid-sized brands; however, their effectiveness is often constrained by digital readiness and uneven supplier participation. The meta-analysis concludes that traceability in apparel manufacturing is not merely a technical challenge but a deeply institutional and organizational endeavor. Effective traceability systems require alignment across governance frameworks, platform interoperability, and equitable stakeholder involvement to move beyond surface-level compliance and achieve meaningful transparency across the entire apparel value chain.

Keywords

Supply Chain Traceability; Real-Time Order Tracking; Vendor Management Systems; Export Visibility; Apparel Manufacturing

Citation

Limon, G. Q. (2022). *Supply chain traceability in apparel manufacturing: A review of real-time order tracking, vendor management, and export visibility systems*. *International Journal of Scientific Interdisciplinary Research, 1*(1), 1–26. https://doi.org/10.63125/dj9fgy65

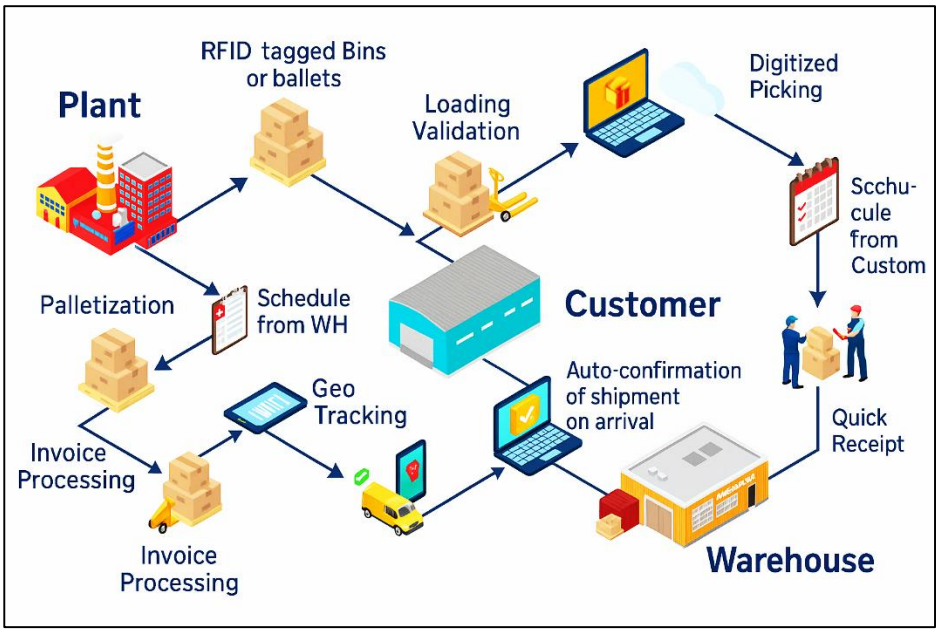
Received: September 12, 2022
Revised: October 15, 2022
Accepted: November 27, 2022
Published: December 07, 2022

https://doi.org/10.63125/dj9fgy65

INTRODUCTION

Supply chain traceability refers to the ability to identify and track the history, application, or location of products and their components throughout the production and distribution process (Agrawal et al., 2021) In the context of apparel manufacturing, traceability encompasses the systematic documentation of each step, from raw material sourcing to the delivery of finished garments to the final consumer (Hu et al., 2013). This concept is distinct from transparency, though both are often intertwined. Traceability emphasizes factual, verifiable data regarding origin, handling, and transformation, whereas transparency relates more broadly to the openness of such information (Bechini et al., 2008). As apparel supply chains become more global and complex, involving multiple stakeholders across various geographies, the demand for robust traceability mechanisms grows (He et al., 2008). The apparel sector, notorious for labor exploitation and environmental degradation, has been particularly pressured by consumers, regulators, and NGOs to implement traceability to ensure ethical and sustainable practices. According to McKinsey & Company (2020), over 70% of global fashion executives have cited traceability as a top priority for supply chain transformation. Thus, traceability is no longer a luxury but a prerequisite for corporate responsibility, market access, and competitive differentiation. It also plays a pivotal role in complying with international trade regulations, such as the European Union's Due Diligence Law (European Commission, 2021) and the U.S. Uyghur Forced Labor Prevention Act (U.S. Congress, 2021).

Figure 1: Integrated Supply Chain Traceability Flow from Plant to Warehouse via Customer Node

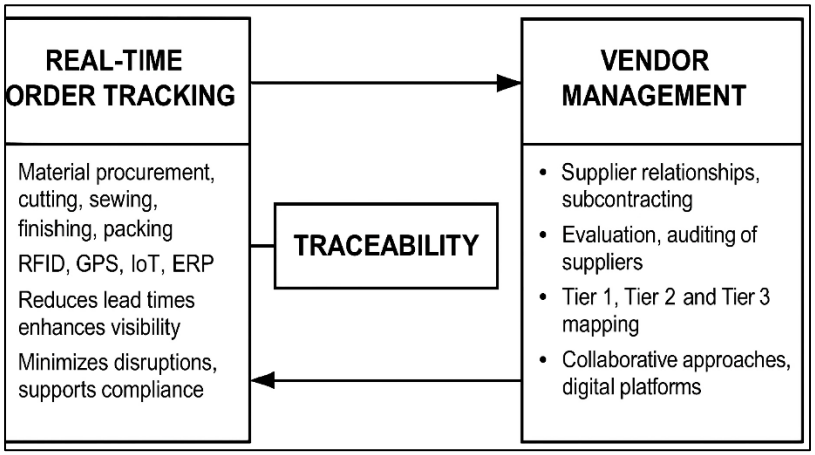


Traceability in apparel manufacturing carries substantial international significance, primarily due to the dispersed nature of global production networks and the growing legislative and market-driven expectations for ethical sourcing. The garment industry contributes significantly to the economies of countries like Bangladesh, Vietnam, India, and China, yet it remains plagued by poor working conditions, subcontracting abuses, and opaque vendor networks (He et al., 2008). To address these challenges, international organizations such as the International Labour Organization and the Organisation for Economic Co-operation and Development have developed guidelines encouraging the adoption of traceability tools. In global markets, brands increasingly rely on traceability systems to verify supplier compliance with labor laws, environmental standards, and quality benchmarks (Agrawal et al., 2018). In Europe, the Sustainable Apparel Coalition has championed the Higg Index, a traceability framework measuring environmental and social impact across the value chain. Similarly, the United Nations Economic Commission for Europe has piloted blockchain-enabled traceability models to enhance data integrity and cross-border visibility in

https://doi.org/10.63125/dj9fgy65

textile supply chains. Without effective traceability, apparel brands risk severe reputational damage, market sanctions, and legal penalties, particularly under new corporate due diligence laws (Fritz et al., 2017). The emphasis on traceability is not solely regulatory; consumers in North America and Europe increasingly demand ethical sourcing, placing social accountability and transparency at the heart of their purchasing decisions. In response, traceability has become embedded within international trade compliance, supplier contracts, and sustainability reporting frameworks (Freise & Seuring, 2015).

Figure 2: Interrelationship Between Real-Time Order Tracking and Vendor Management



The objective of this review is to critically synthesize academic and industry-based literature on supply chain traceability in apparel manufacturing, with specific attention to three core components: real-time order tracking, vendor management, and export visibility systems. This synthesis seeks to offer a structured and evidence-based understanding of how traceability mechanisms function across various operational layers of apparel production and distribution. By categorizing and analyzing existing empirical studies, technological frameworks, and case-specific implementations, the review aims to provide a consolidated reference point for scholars, industry practitioners, and policymakers. The focus on real-time order tracking is intended to illuminate how digital tracking systems enhance production responsiveness, minimize uncertainties, and optimize logistical coordination in fast-paced manufacturing environments. Meanwhile, the analysis of vendor management systems is aimed at examining how apparel brands engage with supplier networks to uphold labor, environmental, and quality standards across tiers of production. Furthermore, the review targets export visibility systems as a distinct, though interconnected, domain of traceability that plays a crucial role in maintaining transparency through international trade routes, especially for compliance with transnational laws and voluntary certification regimes. By establishing a triadic framework of analysis, the review intends to uncover the synergies and frictions among these components, recognizing that effective traceability is not confined to one stage or actor but emerges from coordinated digital and organizational practices across the entire supply chain. The review also seeks to identify recurring themes, such as technological interoperability, supplier resistance, governance bottlenecks, and the impact of traceability on operational performance. The literature reviewed spans diverse geographical contexts and organizational sizes, allowing the study to reflect both global trends and regional specificities. Ultimately, the objective is to present a comprehensive, critical, and nuanced portrayal of traceability in apparel manufacturing—one that moves beyond normative calls for transparency to empirically grounded insights into its mechanisms, challenges, and operationalization across production ecosystems.

LITERATURE REVIEW

The body of scholarly and industry literature concerning supply chain traceability in apparel manufacturing has grown substantially in recent decades, paralleling the increasing globalization of garment production and the intensified scrutiny from stakeholders demanding ethical,

https://doi.org/10.63125/dj9fgy65

transparent, and sustainable operations. This literature review endeavors to critically examine and synthesize the existing body of knowledge across three fundamental domains: real-time order tracking, vendor management systems, and export visibility mechanisms. These categories reflect the multi-dimensionality of traceability in apparel supply chains, spanning upstream sourcing practices, midstream production accountability, and downstream logistics transparency. Existing studies cover a wide array of technologies, governance models, regulatory frameworks, and market-based initiatives that influence traceability practices. While some focus on technological innovations—such as the application of RFID, blockchain, and enterprise systems—others explore institutional dimensions like compliance regimes, supplier behavior, and cross-border regulations. Several case studies have documented brand-specific initiatives, while comparative studies have highlighted regional discrepancies in implementation due to differences in digital infrastructure, labor laws, and supply chain complexity. This section does not merely catalog these contributions; instead, it presents an organized, thematic synthesis to expose the underlying dynamics, gaps, and converging patterns within traceability discourse. To that end, the literature review is structured into five core thematic segments, each anchored in a specific operational domain of apparel manufacturing. These themes allow for a deeper engagement with both technological enablers and socio-organizational structures, ultimately offering a holistic understanding of how traceability is conceptualized, implemented, and evaluated across the apparel industry.

Traceability in Apparel Supply Chains

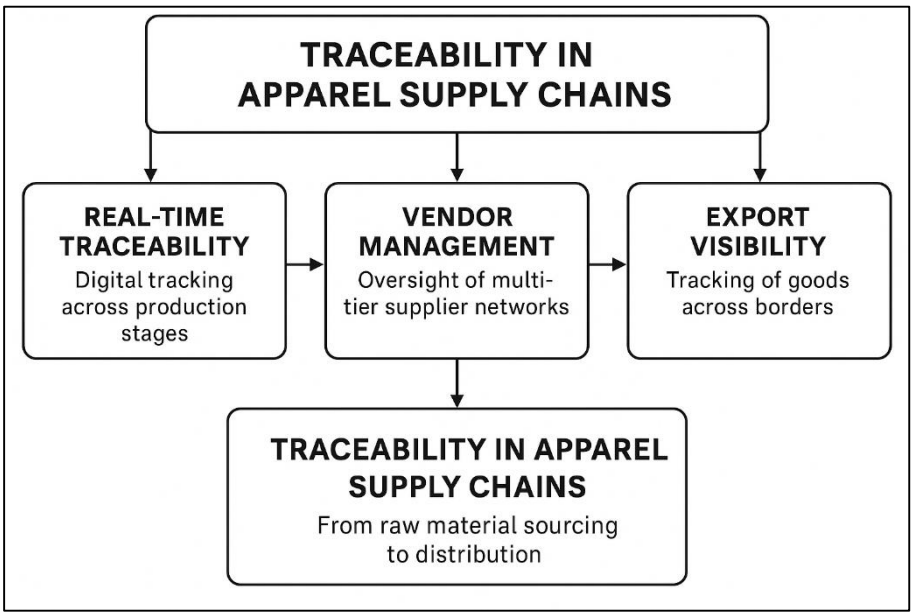
Traceability in apparel supply chains is a central mechanism for operational governance, quality assurance, and ethical oversight. It enables firms to document the movement and transformation of products through the various tiers of manufacturing, from raw material procurement to end-user distribution (Rebs et al., 2017). The concept is often distinguished from, but closely linked to, transparency and accountability (Chen et al., 2017). Traceability emphasizes data reliability, auditability, and the verifiable origin of materials, while transparency refers to the openness and accessibility of that information to stakeholders. As Boström and (Cachon & Fisher, 2000) argue, the enforcement of social and environmental norms in global garment production depends significantly on robust traceability infrastructures. In fragmented and outsourced production networks, traceability offers a structured approach to manage risks related to labor rights violations, environmental hazards, and unauthorized subcontracting (Gobbi & Massa, 2015). Empirical studies confirm that traceability improves supply chain monitoring and reduces the occurrence of undocumented production (Kumar et al., 2016). Brands operating in countries with limited regulatory enforcement, such as Bangladesh, Cambodia, and Myanmar, use traceability tools to maintain compliance with international labor standards (Giannakis & Papadopoulos, 2016). Moreover, traceability mechanisms have been embedded within compliance frameworks such as the Social & Labor Convergence Program (SLCP) and the Better Work Program, promoting consistent documentation practices. Although some scholars critique audit-centric approaches for being susceptible to falsification and cost-shifting to suppliers (Sunny et al., 2020), traceability provides baseline data that enables risk mapping and remediation strategies. These systems are particularly relevant for meeting the due diligence obligations mandated by the European Union and the United States, which require documentation of supply chain processes beyond Tier 1. Therefore, traceability functions as a foundational capability that underpins regulatory compliance, ethical sourcing, and supply chain accountability in apparel manufacturing.

Real-time traceability in apparel manufacturing is increasingly enabled by digital technologies that integrate data capture, transmission, and analysis across production stages. Radio Frequency Identification (RFID), Internet of Things (IoT) sensors, and cloud-based enterprise resource planning (ERP) platforms facilitate the monitoring of materials, work-in-progress (WIP), and finished goods as they move through cutting, sewing, finishing, and packing (Seuring et al., 2008). These technologies improve production visibility, reduce lead times, and minimize errors caused by manual data entry or communication delays (Closs et al., 2010). In the context of fast fashion, where short turnaround times are critical, real-time tracking has been shown to support agile manufacturing strategies by enabling continuous flow production and dynamic scheduling. Brands

https://doi.org/10.63125/dj9fgy65

like Zara and Uniqlo leverage such systems to synchronize production and logistics activities with demand signals from retail stores. Studies also highlight that real-time tracking systems assist in quality control and inventory accuracy, thereby reducing overproduction and unsold stock (Gold et al., 2010; Seuring et al., 2008). Wognum et al. (2011) demonstrate that the integration of traceability tools with manufacturing execution systems (MES) enables timestamped visibility of operations, which is essential for internal audits and buyer verification. RFID-enabled apparel production units in Vietnam and India report significant efficiency gains and reduced production bottlenecks (Lam & Postle, 2006). While high setup costs and interoperability challenges have constrained wider adoption in small and medium enterprises (SMEs), real-time traceability systems are increasingly scalable through mobile applications and cloud services (Madumidha et al., 2019). Ultimately, these digital infrastructures ensure data continuity across production stages, reinforcing traceability and enabling brands to authenticate their sourcing and production claims with empirical evidence (de Brito et al., 2008).

Figure 3: Simplified Framework of Traceability Functions Across Apparel Supply Chain Phases



Vendor management constitutes a critical axis of traceability in apparel supply chains, especially given the multi-tiered and geographically dispersed nature of sourcing networks. Apparel brands often rely on Tier 1 suppliers who, in turn, subcontract to Tier 2 and Tier 3 facilities for dyeing, printing, and fabric production, which significantly complicates traceability efforts (Saak, 2016). Mapping these supplier tiers is essential for identifying high-risk nodes and ensuring compliance across the entire production ecosystem. Tools such as vendor scorecards, supply chain mapping software, and centralized compliance databases like Sedex and Open Supply Hub have been widely adopted to enhance traceability. Collaborative vendor governance models, which focus on long-term relationships, capacity building, and information sharing, have shown to be more effective than purely audit-based approaches in sustaining traceability over time (Sarpong, 2014). Garcia-Torres et al. (2021) argue that brands with direct engagement in supplier development are better positioned to trace and influence upstream activities. Furthermore, donor-funded initiatives like the ILO's Better Work program and the Ethical Trading Initiative (ETI) have emphasized multi-stakeholder collaboration to increase traceability across multiple tiers (Marconi et al., 2017). Empirical studies show that traceability improves when vendors are incentivized through performance-linked contracts, compliance credits, or preferred supplier status. However, institutional challenges—such as data withholding, subcontracting opacity, and capacity limitations—persist, particularly among small-scale suppliers in Southeast Asia and Sub-Saharan

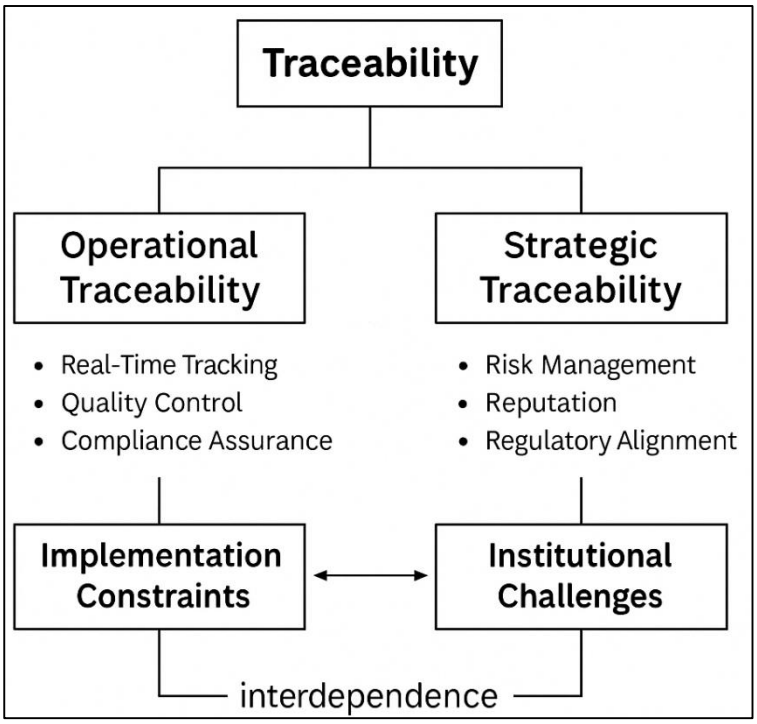
https://doi.org/10.63125/dj9fgy65

Africa (Canavari et al., 2010). These findings underscore the importance of vendor management systems not only as compliance tools but as relational infrastructures that support the continuous flow of traceability data across multiple nodes of the apparel supply chain.

Traceability: Operational vs. Strategic Perspectives

Operational traceability refers to the concrete, day-to-day mechanisms and technologies that allow for the documentation, tracking, and verification of goods and activities throughout the apparel production process. In the apparel industry, these mechanisms are applied across procurement, manufacturing, logistics, and warehousing stages to ensure that each input and transformation is recorded and traceable (Agrawal & Pal, 2019). Real-time tracking systems, barcode scanning, RFID technologies, and ERP platforms form the bedrock of operational traceability infrastructure (Mejías et al., 2019). Studies have shown that the implementation of these tools reduces error rates, improves inventory accuracy, and enhances production synchronization (Egels-Zandén et al., 2015). The operational function of traceability is also vital for ensuring compliance with customer orders, controlling quality, and meeting internal audit standards. In multi-supplier networks, traceability systems help track raw material consumption, monitor subcontractor outputs, and detect inefficiencies in workflows. For example, Gold and Heikkurinen (2018) documented how real-time operational traceability enabled Zara to maintain production agility and reduce turnaround times significantly. Similarly, studies in emerging manufacturing hubs like Vietnam and Bangladesh confirm that RFID and MES integrations improve cut-to-ship visibility and minimize excess inventory. Moreover, operational traceability is crucial for verifying product claims, such as "organic cotton" or "recycled polyester," through batch-level documentation (Fraser et al., 2020). Although operational systems are often seen as logistical tools, they form the technical backbone that supports all traceability objectives, ensuring that trace data is timely, accurate, and verifiable across multiple production stages (Gold & Heikkurinen, 2018).

Figure 4: Operational Mechanisms vs. Strategic Objectives in Apparel Supply Chains



From a strategic standpoint, traceability transcends basic operational monitoring and is embedded into the organizational fabric as a driver of risk management, reputational capital, and regulatory alignment. Apparel firms adopt traceability not merely to optimize production but to achieve strategic goals such as market differentiation, consumer trust-building, and access to regulated

https://doi.org/10.63125/dj9fgy65

markets (Fraser et al., 2020). In this context, traceability becomes a governance tool that enables organizations to signal ethical sourcing, environmental sustainability, and legal compliance to external stakeholders, including consumers, investors, regulators, and NGOs (Gold & Heikkurinen, 2018). The strategic value of traceability is evidenced by its integration into global compliance frameworks such as the OECD Due Diligence Guidelines, the EU Corporate Sustainability Due Diligence Directive, and the U.S. Uyghur Forced Labor Prevention Act (Egels-Zandén et al., 2015). Several empirical studies emphasize that traceability is a prerequisite for market access in Europe and North America, particularly for brands that publicly commit to human rights and environmental performance (Mejías et al., 2019). Strategic traceability also aligns with brand values and corporate social responsibility (CSR) programs, creating a reputational shield against scandals related to labor exploitation or environmental violations. For instance, companies such as Patagonia and Levi Strauss have built traceability into their sourcing strategies as a branding mechanism and supply chain control tool (Agrawal & Pal, 2019). Additionally, traceability supports certification schemes like GOTS, OEKO-TEX, and Fair Trade, all of which demand rigorous documentation and audit trails.

Theoretical Underpinnings

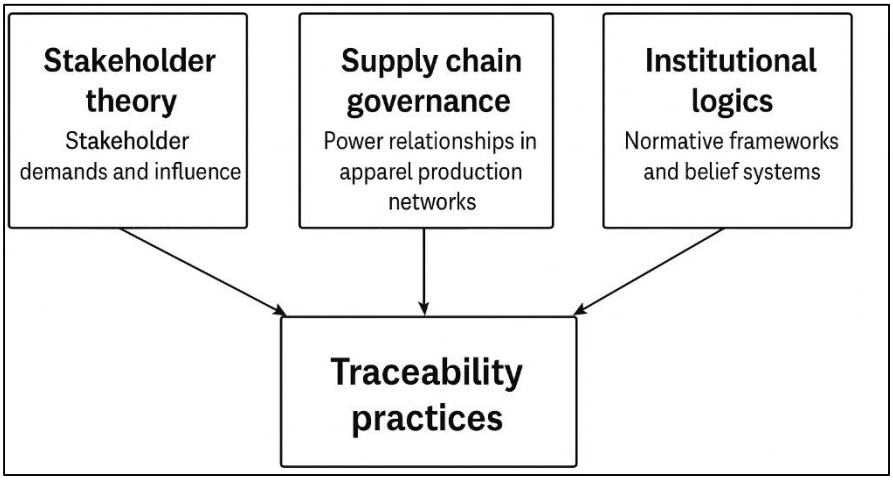
Stakeholder theory provides a foundational lens through which the complexity of apparel supply chain traceability can be interpreted. Originating from (Freeman, 2010) proposition that organizations must account for the interests of all stakeholders—not just shareholders—this framework has been widely applied in studies examining corporate social responsibility (CSR), transparency, and ethical governance in global supply chains (He et al., 2008; Rudell, 2006) In apparel manufacturing, stakeholders include not only investors and customers, but also workers, NGOs, governments, certification bodies, and community members, each exerting normative or coercive pressure on brands to disclose sourcing practices (Huq et al., 2016). The stakeholder landscape is especially pronounced in apparel due to high-profile labor scandals and environmental controversies, which have increased the reputational risks associated with opaque supply chains. Studies show that stakeholder influence significantly affects firms' willingness to invest in traceability infrastructure, particularly in contexts where consumers are vocal, and NGOs act as watchdogs (Ubilava & Foster, 2009). Moreover, stakeholder salience—defined by power, legitimacy, and urgency—determines which actors gain visibility and influence decision-making on traceability (Mantere & Ketokivi, 2013). Research by Theißen et al. (2014) and Juels (2006) suggests that buyers and lead firms often prioritize stakeholder groups that directly impact brand image, such as Western consumers and international regulators, while marginalizing less visible actors such as informal subcontractors or homeworkers. The stakeholder-driven logic also extends to certification schemes like Fair Trade, OEKO-TEX, and GOTS, which act as intermediaries between stakeholders and brands, enforcing traceability through verification protocols. Thus, stakeholder theory provides a robust explanatory model for understanding the motivation and asymmetry behind traceability practices in apparel supply chains.

Supply chain governance refers to the structures, rules, and mechanisms through which lead firms control and coordinate activities across multi-tiered production networks. Kshetri (2018) distinguished between different governance types—market, modular, relational, captive, and hierarchical—based on power asymmetries and interdependence between buyers and suppliers. In the apparel sector, governance is predominantly buyer-driven, meaning brands exert substantial influence over pricing, design, delivery schedules, and compliance requirements (Pal & Yasar, 2020). This governance model enables brands to enforce traceability requirements by setting contractual obligations, conducting audits, and deploying digital monitoring tools. However, it also leads to uneven traceability responsibilities, with most burdens shifted onto suppliers, especially in the Global South. Studies have highlighted that while buyers set traceability expectations, they often provide limited resources or incentives to support implementation at the supplier level. Governance structures influence not only operational traceability but also the depth of supplier mapping, the rigor of verification practices, and the frequency of data collection (Agrawal et al., 2020). For example, hierarchical governance—where the buyer owns or directly controls production—tends

https://doi.org/10.63125/dj9fgy65

to yield higher traceability, while market-based models relying on arm's-length transactions show weaker documentation and oversight. The presence of third-party governance through multi-stakeholder initiatives (MSIs) such as the Ethical Trading Initiative (ETI) and the Better Work program further complicates the landscape by introducing overlapping rules and performance benchmarks (Agrawal et al., 2021). These governance layers collectively structure how traceability is distributed, enforced, and monitored across apparel supply chains.

Figure 5: Integrated Theoretical Framework for Traceability in Apparel Supply Chains



Institutional logics refer to the broader belief systems, practices, and cultural assumptions that shape organizational behavior and decision-making (Longo et al., 2019). Within apparel supply chains, competing institutional logics—such as commercial efficiency, ethical compliance, and legal conformity—coexist and often conflict, influencing how traceability is interpreted and operationalized. For instance, brands may face tension between market-driven logics prioritizing cost and speed, and sustainability-driven logics emphasizing social responsibility and environmental stewardship. These logics are embedded in organizational routines and reflected in how traceability systems are adopted, customized, and maintained (Helo & Hao, 2019). Institutional pressures manifest through mimetic (copying industry leaders), coercive (regulatory), and normative (professional or ethical standards) mechanisms. Apparel firms operating under strong institutional scrutiny—due to consumer activism, media attention, or regulatory exposure—tend to adopt more comprehensive traceability frameworks, often extending beyond first-tier suppliers (Pagell & Wu, 2009). Research shows that institutional context explains variation in traceability practices across regions; for example, EU-based firms often report deeper supplier engagement due to stricter CSR norms, while firms in less regulated environments rely more heavily on self-declared compliance. Institutional logics also shape internal trade-offs, such as choosing between short-term financial returns and long-term traceability investments. The combined application of stakeholder theory, supply chain governance, and institutional logics offers a comprehensive analytical framework to interpret the multi-dimensional nature of traceability in apparel supply chains. While stakeholder theory highlights the pluralistic demands placed on brands by external actors, governance theory emphasizes how power relations and structural controls determine traceability implementation (Agrawal et al., 2021; Pal et al., 2019). Institutional logics, in contrast, explain the internal rationales and belief systems that drive organizational behavior beyond mere compliance (Kumar et al., 2017). Together, these theories enable a deeper understanding of both agency and structure in the adoption and performance of traceability systems. For instance, Caniato et al. (2012) found that despite similar stakeholder pressures, brands with captive governance models and sustainability-aligned institutional cultures invested significantly more in traceability infrastructure than others operating under market-based or modular governance. Meanwhile, empirical studies by Alemanno (2010) demonstrate that traceability failures often result not from lack of technology

https://doi.org/10.63125/dj9fgy65

but from organizational misalignment across stakeholder demands, governance frameworks, and institutional beliefs. Even within the same multinational firm, traceability initiatives can differ dramatically across regional offices due to variations in local norms, stakeholder salience, and institutional expectations (Lotfi et al., 2013). This layered approach reveals the value of multi-theoretical analysis in capturing the political, economic, and cultural dimensions of traceability. It also clarifies why traceability remains unevenly implemented and differentially understood across the global apparel landscape, despite widespread agreement on its importance (Lambert & Cooper, 2000). Therefore, these intersecting theories serve not as isolated conceptual tools but as mutually reinforcing perspectives that together explain the empirical patterns and institutional complexity of traceability practices.

ERP and SCM Systems in Garment Production

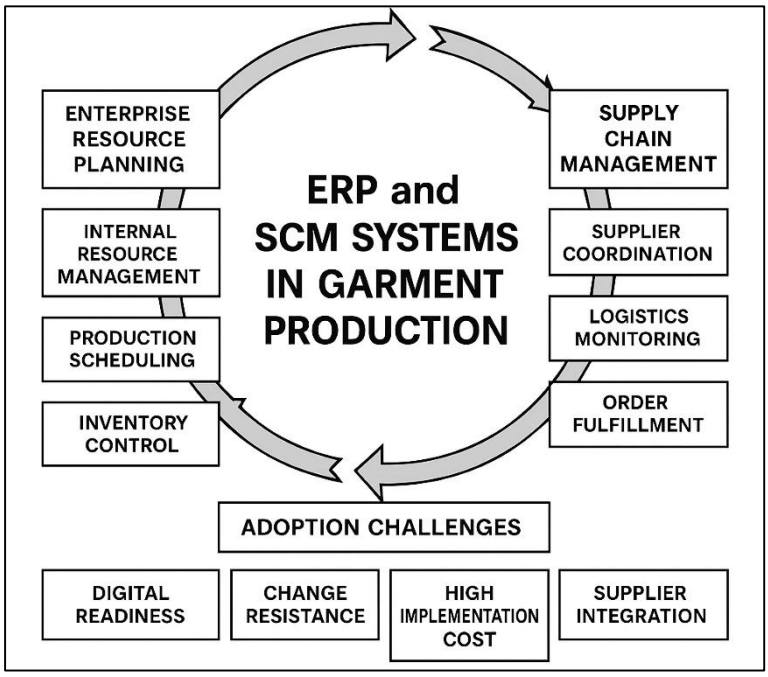
Enterprise Resource Planning (ERP) systems serve as critical digital infrastructure for data integration, operational coordination, and real-time visibility in garment production. These systems consolidate data across functional domains—procurement, inventory, production planning, order fulfillment, finance, and human resources—into a unified platform that enhances traceability and decision-making accuracy (Henninger, 2015). In the garment industry, where lead times are tight and product variety is high, ERP systems facilitate the synchronization of material requirements with production schedules, reduce stockouts, and ensure timely order delivery (Lotfi et al., 2013). Empirical studies confirm that ERP adoption reduces production delays, improves internal communication, and minimizes data redundancy (Henninger, 2015). For instance, Marconi et al. (2017) demonstrated how ERP-enabled workflow monitoring reduced processing time by 22% in a mid-sized apparel firm in China. Additionally, integration with barcode or RFID-based tracking systems enhances visibility into the movement of goods at each processing stage (Gold et al., 2010). ERP systems like SAP AFS (Apparel and Footwear Solution) and Infor CloudSuite have been tailored to address industry-specific challenges such as size-color matrix management, style seasonality, and rapid order change management (Srivastava et al., 2015). However, successful implementation hinges on change management, user training, and legacy system compatibility (Cheng et al., 2013). Furthermore, ERP's data-driven capabilities enhance the operational layer of traceability, ensuring that production inputs, supplier sources, and inventory movements are digitally documented, auditable, and aligned with compliance protocols (Pal & Gander, 2018). Therefore, ERP systems function as both enablers of process efficiency and foundational platforms for traceability documentation across the internal garment production cycle.

Supply Chain Management (SCM) systems in garment production extend the traceability function beyond internal operations by enabling brands to monitor, coordinate, and control supplier networks, logistics flows, and customer orders across geographies. SCM systems integrate data from suppliers, logistics partners, and retailers to ensure supply chain continuity, transparency, and responsiveness (Theißen et al., 2014). In the apparel industry, these systems are particularly important due to the extensive reliance on offshore and multi-tiered sourcing arrangements (Kwok & Wu, 2009). Research shows that SCM platforms like Infor Nexus and Oracle SCM Cloud allow brands to track purchase orders, shipment schedules, quality inspections, and vendor compliance status in real time. SCM tools also support the allocation of materials across orders, balancing supplier capacity and reducing overproduction and waste (Carbonara & Giannoccaro, 2009). A study by Wang et al. (2019) noted a 28% improvement in production agility and a 19% reduction in raw material excess among garment manufacturers using advanced SCM analytics. Moreover, SCM systems often include supplier onboarding modules, which allow for documentation of certifications, labor audits, and environmental assessments, facilitating vendor traceability (Carbonara & Giannoccaro, 2009). In buyer-driven governance structures, SCM systems act as digital command centers from which compliance and performance expectations are communicated and enforced (Lotfi et al., 2013). Despite their potential, implementation challenges persist, including system interoperability with supplier platforms, data accuracy concerns, and high setup costs (Kembro et al., 2017). Nevertheless, SCM systems represent essential infrastructure for managing external traceability, extending visibility into supplier behavior, logistics integrity, and

https://doi.org/10.63125/dj9fgy65

distribution pathways.

Figure 6: ERP and SCM Integration for Enhanced Traceability in Garment Production

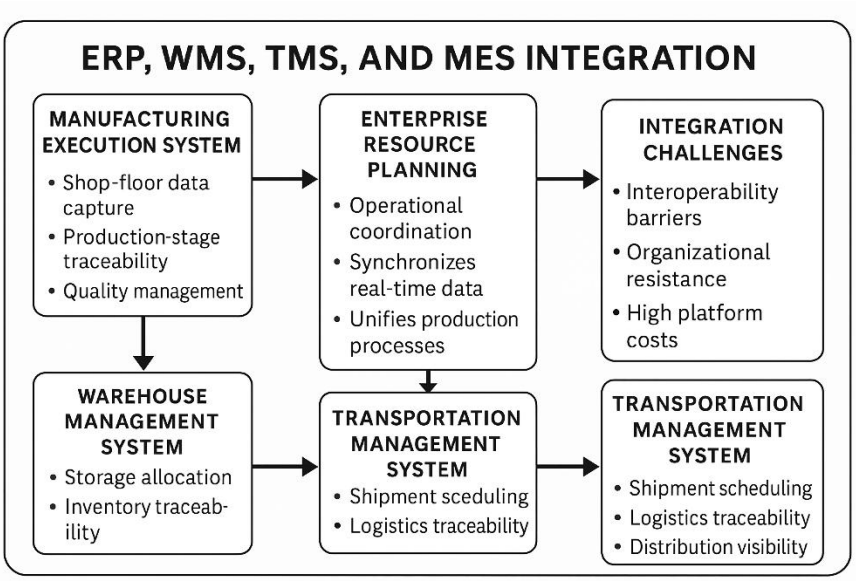


ERP, WMS, TMS, and MES Integration

Manufacturing Execution Systems (MES) play a critical role in garment production by capturing shop-floor data, linking machine operations to production plans, and providing traceability at the micro-level of fabric handling, stitching, finishing, and packaging (Lotfi et al., 2013). MES integration with ERP enhances visibility by synchronizing real-time factory data with upstream planning and downstream delivery processes (Tu et al., 2018). This bidirectional communication allows discrepancies in output, quality, or labor allocation to be immediately visible to both production and planning teams, improving corrective action and audit readiness (Lotfi et al., 2013). In garment factories, MES is especially valuable for tracing defects back to specific workstations or operators, a feature critical for managing quality assurance and buyer inspections (Kembro et al., 2017). Moreover, MES captures time stamps for each activity, enabling traceability of production cycles and the tracking of idle time, rework, and overtime—factors linked to both cost efficiency and labor compliance. When paired with RFID or barcode inputs, MES provides granular trace data that feeds into ERP systems, enriching the traceability log and supporting compliance reporting. Studies by Nativi and Lee (2012) and Li et al. (2017) show that integrated MES-ERP setups enable deeper supplier monitoring, especially when lead firms manage vertically integrated or semi-captive production models. Despite the benefits, challenges remain, such as MES customization for garment-specific tasks (e.g., embroidery or multi-style runs) and resistance from operators due to digital fatigue or skill gaps (Reefke & Sundaram, 2017). Nevertheless, MES-ERP integration is fundamental for achieving production-stage traceability that meets both operational needs and buyer-driven compliance mandates.

https://doi.org/10.63125/dj9fgy65

Figure 7: ERP, WMS, TMS, and MES Integration Framework for End-to-End Apparel Supply Chain Traceability



Warehouse Management Systems (WMS) and Transportation Management Systems (TMS) are critical for maintaining traceability across storage, staging, and global distribution phases in garment supply chains. WMS software supports inventory allocation, bin management, batch control, and cycle counting, allowing apparel firms to trace material movement within and across storage sites (Kwok & Wu, 2009). TMS, in turn, facilitates transportation visibility by coordinating shipment schedules, optimizing carrier selection, and generating export documentation—all of which are essential for regulatory and customs compliance (Lumsden & Mirzabeiki, 2008). When WMS and TMS are integrated with ERP and MES, a seamless data bridge is formed that enables order-specific tracking from production line to port dispatch (Agrawal et al., 2021). For instance, integration allows garment labels to be printed at packing based on real-time order data, ensuring alignment with retail requirements and export logistics (Longo et al., 2019). In regions like South Asia, where apparel exports represent a substantial share of GDP, WMS-TMS integration ensures traceability in container loading, order bundling, and shipping documentation (Helo & Hao, 2019). Moreover, TMS platforms integrated with blockchain or EDI frameworks improve the integrity of shipment records, providing immutable, timestamped data that support chain-of-custody claims (Pagell & Wu, 2009). Several brands operating in the U.S. and Europe require digital proof of export traceability to comply with legislation such as the Uyghur Forced Labor Prevention Act and EU Green Claims rules. However, the effectiveness of WMS-TMS systems depends on digital readiness, port infrastructure, and the willingness of 3PL providers to integrate data feeds. These challenges notwithstanding, WMS-TMS integration remains a pivotal component of downstream apparel traceability.

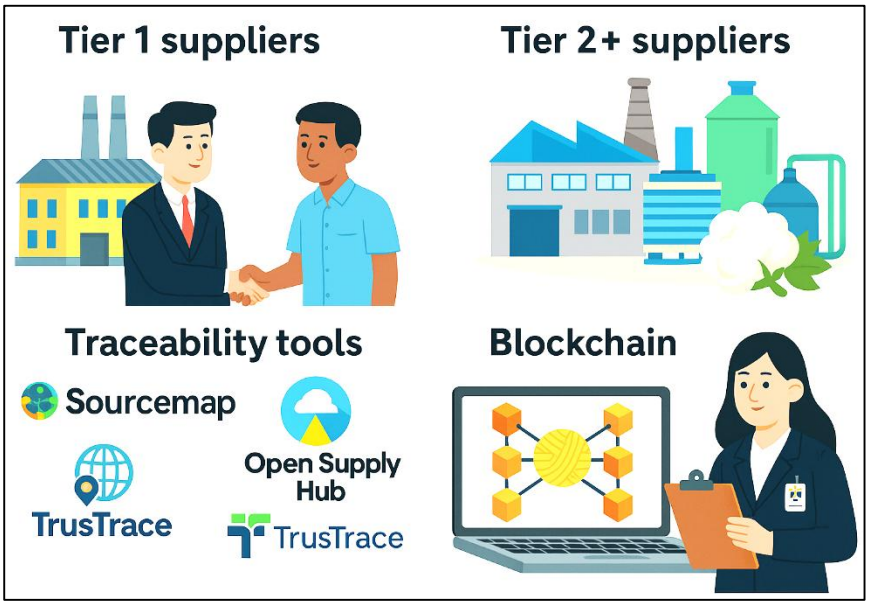
Tier 1 vs. Tier 2+ Mapping

The concept of supplier tiering is fundamental to understanding visibility and control in apparel supply chains. Tier 1 suppliers typically refer to direct business partners—factories and manufacturers with whom brands maintain contractual relationships—while Tier 2 and beyond represent upstream entities such as fabric mills, dye houses, and raw material processors (Freise & Seuring, 2015). The distinction is critical in traceability practices, as brands generally maintain comprehensive oversight over Tier 1 actors but possess limited or no visibility into Tier 2 and Tier 3 operations (Fritz et al., 2017). Research by Agrawal et al. (2018) shows that major fashion brands tend to audit Tier 1 facilities while leaving upstream activities unmonitored, despite the fact that many labor violations and environmental abuses occur in these deeper tiers. Subcontracting, especially informal or unauthorized forms, further obscures visibility beyond Tier 1 (Marucheck et al., 2011). Additionally, because Tier 2+ suppliers are often several layers removed from the buyer, there is limited incentive for these actors to align with traceability protocols unless explicitly

https://doi.org/10.63125/dj9fgy65

required through tier mapping or contractual cascades (Kwok & Wu, 2009). These issues are compounded by geographic dispersion, inconsistent regulation, and limited digital infrastructure in countries such as Bangladesh, India, Vietnam, and Ethiopia, where upstream production is concentrated (He et al., 2008). Mapping efforts that stop at Tier 1 therefore fail to capture the full spectrum of risk and operational complexity in global apparel production, undermining traceability initiatives and ethical sourcing commitments (Gobbi & Massa, 2015). Consequently, tier differentiation not only shapes supply chain governance but also influences the scope and depth of traceability data collected across the apparel sector (Cachon & Fisher, 2000).

Figure 8: Multi-Tier Supplier Mapping and Digital Traceability Tools in Apparel Supply Chains



Traceability beyond Tier 1 presents numerous technical, logistical, and organizational challenges. While Tier 1 suppliers are often digitally connected through ERP or SCM systems and subject to regular audits, Tier 2+ suppliers typically operate under informal arrangements or subcontracted agreements, making them difficult to identify and monitor (Kumar et al., 2016). Sunny et al. (2020) highlight that Tier 2+ mapping is frequently impeded by supplier opacity, lack of standardized documentation, and limited cooperation from intermediaries. Upstream actors, such as dyeing units and textile mills, may serve multiple buyers and therefore resist disclosing client lists or proprietary processes (Brito et al., 2008). Moreover, cost pressures in apparel manufacturing incentivize concealment, particularly when non-compliant subcontractors offer price advantages (Sarpong, 2014). Empirical evidence suggests that even in programs that encourage transparency—such as the Social & Labor Convergence Program (SLCP) or Open Supply Hub—mapping beyond Tier 1 is only partial, relying heavily on voluntary disclosures and fragmented databases (Marconi et al., 2017). Additionally, the lack of legal frameworks in many sourcing countries means that brands cannot mandate disclosure beyond their direct suppliers without local enforcement support (Canavari et al., 2010). While technologies like blockchain and supply chain mapping tools have been proposed as solutions, their effectiveness is contingent on data integrity and supplier participation, both of which are low in Tier 2+ environments. As such, Tier 2+ traceability often depends on relational governance, buyer influence, and multistakeholder coordination rather than system-level enforcement (Garcia-Torres et al., 2021). These structural barriers underscore the complexity of extending traceability efforts beyond first-tier partnerships.

Collaborative vs. Coercive Vendor Governance Models

Collaborative and coercive vendor governance models represent two distinct approaches to managing supplier relationships in global apparel supply chains. Coercive governance is

characterized by unilateral control mechanisms, including top-down audits, rigid compliance codes, and contractual enforcement driven by buyers' demands (Schenkel et al., 2015). In contrast, collaborative governance emphasizes joint problem-solving, trust-building, knowledge sharing, and long-term engagement between buyers and suppliers. These models are not mutually exclusive, but rather exist on a continuum, with many apparel firms employing hybrid strategies depending on supply chain tier, geography, and product complexity (Khurana & Ricchetti, 2016). Doorey (2011) have argued that coercive mechanisms are effective in ensuring short-term compliance, particularly under intense regulatory scrutiny or reputational pressure, but often fail to generate sustainable improvements in labor conditions or traceability. Collaborative governance, by contrast, has been linked to better supplier buy-in, improved capacity for compliance, and more durable institutional change. This distinction becomes crucial in traceability initiatives, where deep supplier engagement is necessary for mapping Tier 2+ actors and collecting accurate data (Fraser et al., 2020). While coercive models rely on formal authority and performance sanctions, collaborative approaches invest in supplier training, joint monitoring platforms, and incentive-based compliance frameworks. These theoretical distinctions underscore the divergent philosophies underlying vendor governance and set the stage for empirical evaluations of their effectiveness in diverse apparel sourcing contexts.

Coercive governance has long dominated the apparel industry, particularly through mechanisms such as codes of conduct, third-party audits, corrective action plans, and compliance checklists. These tools reflect buyer-centric power structures that seek to enforce social and environmental standards across global supply chains (Gold & Heikkurinen, 2018). Studies have documented the operational benefits of coercive governance, including rapid standardization, documentation control, and reduced legal liability for brands. However, several scholars criticize this model for fostering superficial compliance or "audit fatigue," where suppliers focus on passing inspections rather than embedding sustainable practices (Mejías et al., 2019). Empirical evidence from Bangladesh, India, and Cambodia indicates that coercive auditing systems often incentivize data manipulation, selective disclosure, and temporary fixes rather than root-cause remediation. Moreover, suppliers frequently bear the financial and administrative burden of compliance, leading to resentment, distrust, and reduced willingness to cooperate in deeper traceability efforts (Marconi et al., 2017). While coercive systems can enforce traceability at Tier 1, their effectiveness declines in Tier 2 and beyond, where buyer leverage is weaker and contractual ties are absent. Studies also reveal that coercive governance often fails to accommodate local labor norms, infrastructural limitations, or informal production systems, reducing its legitimacy and practical utility (Garcia-Torres et al., 2021). As such, while coercive governance may produce short-term gains in visibility and standardization, it often undermines the trust and collaboration necessary for sustained traceability and ethical sourcing in complex apparel ecosystems.

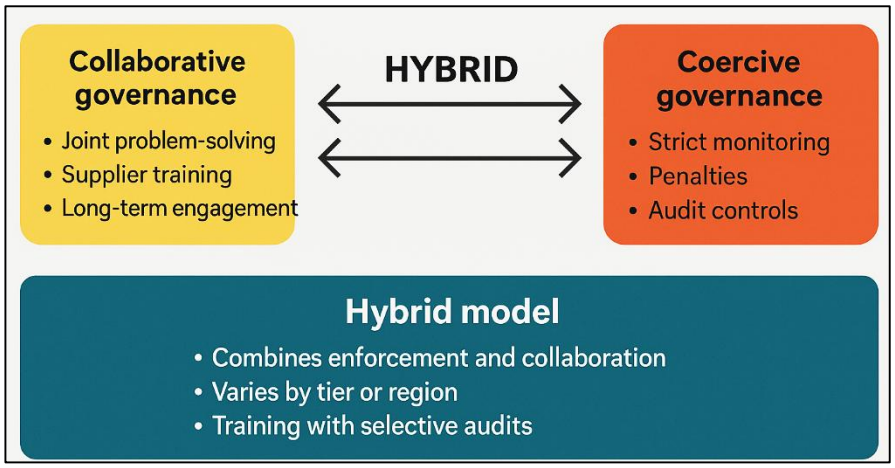
Blockchain and EDI in Cross-Border Shipment Tracking

Electronic Data Interchange (EDI) has long served as a standardized digital communication method in cross-border shipment tracking, facilitating structured data exchange between apparel manufacturers, freight forwarders, customs authorities, and buyers (Wang et al., 2019). EDI allows for real-time transmission of purchase orders, shipping notifications, invoices, and customs declarations using structured formats such as ANSI X12 and UN/EDIFACT (Zyskind et al., 2015). This automation reduces manual errors, accelerates processing time, and minimizes customs clearance delays, particularly in time-sensitive apparel logistics (Cruz & Cruz, 2020). Empirical studies show that EDI integration improves inventory turnover, tracking accuracy, and transaction transparency, especially when aligned with Transportation Management Systems (TMS) and Warehouse Management Systems (WMS) (Fiaidhi et al., 2018). For instance, Choi and Luo (2019) found that global apparel brands using EDI in conjunction with TMS reduced cycle times by over 25% in their Asian export operations. However, EDI remains constrained by limited interoperability, high onboarding costs, and the rigid nature of predefined data formats (Zhang et al., 2019). Smaller suppliers and logistics providers in developing countries often struggle with the technical requirements of EDI systems, resulting in exclusion from brand-integrated traceability

https://doi.org/10.63125/dj9fgy65

platforms (Mandolla et al., 2019). Moreover, EDI systems typically offer point-to-point communication and lack the decentralized transparency that many apparel buyers seek for traceability assurance (Helo & Hao, 2019). Nonetheless, EDI continues to underpin cross-border apparel shipment flows as a reliable, though somewhat inflexible, digital tracking tool embedded in customs, freight, and port management processes (Zhang et al., 2019).

Figure 9: Comparative Governance Models for Multi-Tier Traceability in Apparel Supply Chains

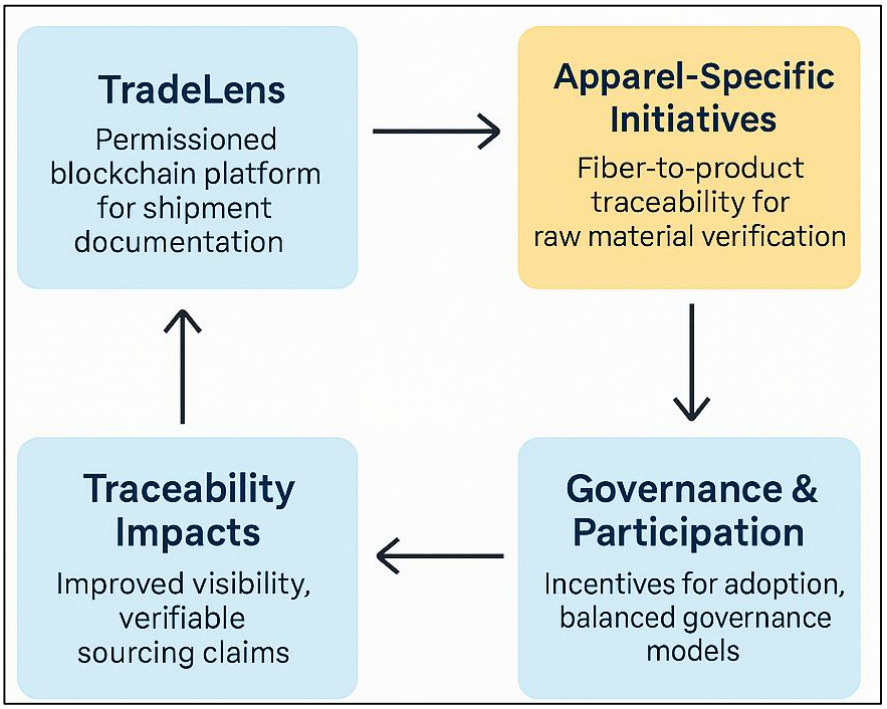


TradeLens and Other Blockchain Initiatives in Apparel Logistics

TradeLens, developed by IBM and Maersk, is one of the most prominent blockchain initiatives applied to global shipping and logistics, offering decentralized documentation and container visibility that has gained traction in the apparel sector (Abdullah Al et al., 2022; Jensen et al., 2019). Operating as a permissioned blockchain platform, TradeLens enables stakeholders—such as shipping lines, port operators, customs authorities, and apparel brands—to access a shared ledger of immutable records for each shipment (Anika Jahan et al., 2022). In cross-border apparel logistics, where container congestion, transit delays, and document fraud are common, TradeLens offers transparency by timestamping critical events such as cargo loading, customs clearance, and handovers (Jovanovic et al., 2022; Khan et al., 2022). Empirical studies show that brands using TradeLens report improved trust among supply chain actors, reduced demurrage costs, and enhanced real-time access to shipment milestones (Rahaman, 2022; Yang, 2019). Apparel exporters in Asia have noted its role in minimizing customs hold-ups through faster data exchange between authorities and logistics partners. However, the platform's effectiveness relies on ecosystem participation; ports and logistics actors that do not integrate remain blind spots in the traceability chain (Jansen-Vullers et al., 2003; Masud, 2022). Furthermore, TradeLens primarily digitizes the container journey rather than providing upstream traceability from raw material to finished garment (Hossen & Atiqur, 2022; Yang, 2019). Despite these limitations, TradeLens remains a reference point for blockchain-enabled shipment documentation, offering a verifiable ledger that complements compliance mandates under frameworks such as the U.S. Uyghur Forced Labor Prevention Act and EU due diligence laws. It has emerged as a partial yet scalable tool for reinforcing downstream transparency in apparel logistics.

https://doi.org/10.63125/dj9fgy65

Figure 10: Blockchain-Based Traceability Framework for Apparel Logistics

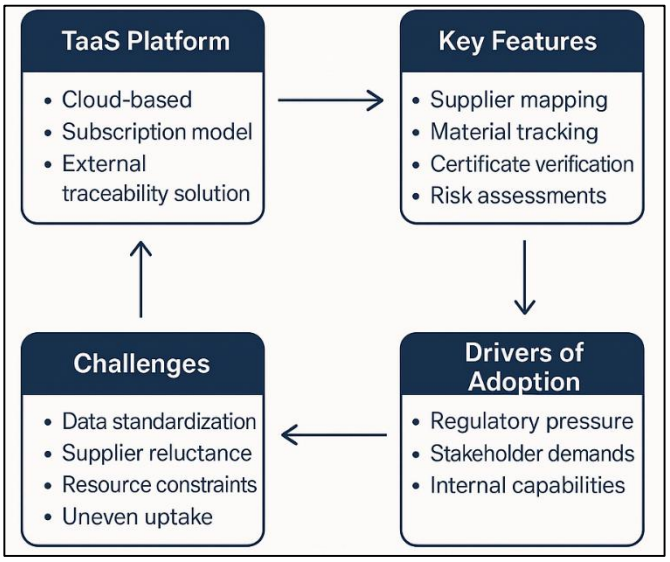


Traceability-as-a-Service (TaaS): Emerging Business Models

Traceability-as-a-Service (TaaS) refers to cloud-based, subscription-driven platforms that offer modular, scalable solutions for tracking supply chain activities without requiring in-house infrastructure. These services deliver traceability tools as externally managed systems, enabling brands to monitor suppliers, materials, certifications, and logistics activities through digital dashboards and integrated data pipelines (Mohan & Ramesh, 2007; Sazzad & Islam, 2022). TaaS platforms have proliferated in the apparel sector due to increasing regulatory pressures, stakeholder scrutiny, and the growing complexity of multi-tiered supply chains (Shaiful et al., 2022). Leading providers such as TrusTrace, TextileGenesis, Sourcemap, and Provenance offer end-to-end visibility tools that allow apparel brands to map supplier networks, upload compliance documents, and verify product origin across raw material, production, and distribution stages (Goswami, 2014; Akter & Razzak, 2022). These platforms typically integrate with existing ERP, SCM, and blockchain tools to minimize data silos and improve process automation (Henninger, 2015). TaaS models benefit especially small and medium-sized enterprises (SMEs) that lack the resources to build proprietary traceability infrastructure, enabling them to comply with brand mandates and access global markets (Pérez et al., 2020). Moreover, TaaS offerings are often aligned with environmental and social certification programs, serving as intermediaries that store, validate, and report sustainability data for ESG audits and legal documentation (Štorga et al., 2011). Despite their advantages, TaaS adoption is shaped by subscription pricing, user accessibility, and compatibility with legacy systems. As a result, TaaS represents a growing service-oriented model for implementing traceability across apparel supply chains with minimal technological disruption and enhanced data centralization.

https://doi.org/10.63125/dj9fgy65

Figure 11: Traceability-as-a-Service (TaaS) Model in Apparel Supply Chains



TaaS platforms offer a diverse array of functionalities tailored to the needs of apparel brands and manufacturers, particularly in tracking orders, managing vendor data, and documenting compliance across jurisdictions. Most platforms include supplier onboarding modules, document repositories, real-time risk flagging systems, and mapping tools that visualize supplier locations and interdependencies (Mejías et al., 2019). Advanced systems also include certificate verification engines linked to standards such as GOTS, OEKO-TEX, SA8000, and BSCI, which automate audit validation and eliminate manual checks. For example, TextileGenesis tokenizes fiber origin data and tracks it digitally through multiple tiers, while TrusTrace offers integration with over 7,000 suppliers globally to streamline the collection of tier-specific information. Sourcemap provides customizable dashboards for sourcing visibility, while Provenance specializes in consumer-facing product-level transparency (Chrysochou et al., 2009). These platforms often support multilingual interfaces and API-based data integration with ERP and blockchain systems, allowing traceability information to be embedded into production and logistics workflows (Agrawal & Pal, 2019). TaaS providers also enable geospatial analytics to identify sourcing hotspots or unauthorized subcontracting practices, a feature increasingly relevant for regulatory compliance under laws like the Uyghur Forced Labor Prevention Act (Garcia-Torres et al., 2019). However, disparities exist in functional maturity; while some platforms support granular, style-level tracking, others operate at a macro level without SKU-specific differentiation (Canavari et al., 2010). These differences influence brand decisions regarding vendor selection and contract inclusion of traceability clauses. Thus, the functional scope of TaaS offerings determines their utility in meeting the unique logistical and compliance needs of apparel supply chains.

The growing adoption of TaaS in the apparel industry is influenced by a confluence of regulatory mandates, reputational concerns, and organizational capabilities. Brands facing due diligence requirements from the EU, the U.S., and Canada have turned to TaaS providers to streamline supplier documentation, chain-of-custody validation, and ESG reporting. Simultaneously, stakeholder expectations for ethical and sustainable sourcing—amplified by NGOs, consumers, and investors—have pressured brands to adopt digital traceability systems as part of their risk management and CSR frameworks (Marconi et al., 2017). Internal drivers also play a significant role: firms with high digital maturity, cross-functional coordination between sourcing and compliance departments, and established ERP or SCM systems find it easier to onboard TaaS platforms (Garcia-Torres et al., 2021). TaaS services are typically delivered through software-as-a-service (SaaS) contracts, with tiered subscription pricing based on user numbers, supply chain complexity, and integration depth (Goswami, 2014). Brands integrate TaaS tools via plug-ins or APIs that link to existing supplier portals or auditing platforms, minimizing disruptions and facilitating scalability.

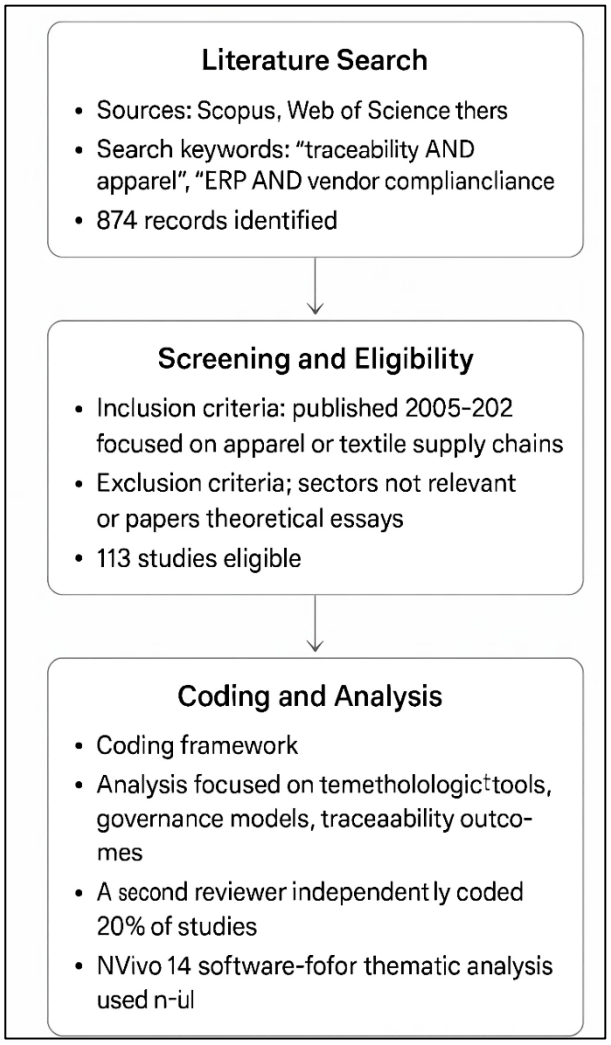
https://doi.org/10.63125/dj9fgy65

In decentralized apparel networks, where suppliers operate across multiple tiers and jurisdictions, TaaS enables centralized oversight with distributed data capture (Pérez et al., 2020). Additionally, collaborative business models are emerging, in which brands subsidize or mandate TaaS use by suppliers, embedding traceability expectations into procurement contracts (Štorga et al., 2011). These approaches create shared accountability but also raise concerns about unequal cost-sharing and digital access gaps, particularly for suppliers in resource-constrained contexts (Mejías et al., 2019). The adoption landscape for TaaS in apparel is thus shaped by both institutional pressures and firm-level strategic alignment.

METHOD

This study adopts a meta-analytical literature review methodology to synthesize and evaluate empirical research on traceability practices in apparel manufacturing. Recognizing the interdisciplinary nature of traceability—which spans supply chain management, digital systems integration, corporate governance, and sustainability—the review integrates both qualitative and quantitative findings from scholarly sources, industry reports, and institutional documentation. The objective is to analyze the deployment and efficacy of traceability mechanisms such as real-time order tracking, vendor oversight tools, export visibility systems, and platform integrations involving ERP, SCM, TMS, MES, and blockchain. The meta-analytic approach allows for the aggregation of recurring patterns, thematic overlaps, governance models, and technological outcomes documented in the literature over the past two decades.

Figure 12: Meta-Analytical Methodological Framework



The review process began with a systematic search of five major academic databases—Scopus, Web of Science, ScienceDirect, ProQuest, and EBSCOhost—supplemented by manual searches of relevant reports from the International Labour Organization (ILO), the Organisation for Economic Co-operation and Development (OECD), and other multilateral bodies. Industry whitepapers from traceability service providers such as TrusTrace, TextileGenesis, SAP, and IBM TradeLens were also consulted. A total of 874 records were initially identified using keyword combinations such as "traceability AND apparel," "ERP AND vendor compliance," "blockchain AND export visibility," and "multi-tier mapping AND textile supply chain." The search was filtered to include studies published between 2005 and 2022, with clear methodological transparency and relevance to apparel or textile-based supply chains. Studies focusing solely on unrelated sectors, theoretical essays without data, and documents lacking English translation were excluded. After screening and eligibility checks, 113 studies were retained for meta-analysis.

Each retained publication was analyzed using a coding framework that captured the authorship, year of publication, region of study, technological tool or platform assessed, governance model (e.g., coercive, collaborative), tier focus (Tier 1 or Tier 2+), methodological orientation, and traceability outcomes. A combination of deductive and inductive coding was used to identify both expected and emergent themes across the dataset. To

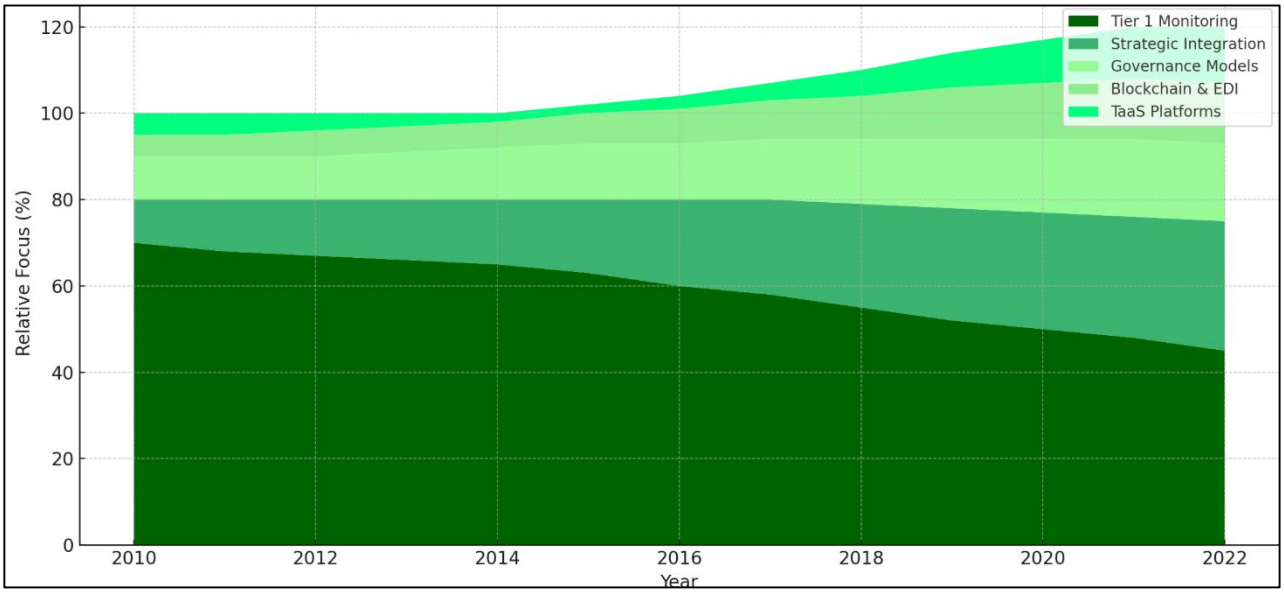
https://doi.org/10.63125/dj9fgy65

ensure reliability, 20% of the documents were independently coded by a second reviewer, achieving a Cohen's kappa coefficient of 0.84. Coding and thematic analysis were conducted using NVivo 14 software, enabling efficient data categorization, retrieval, and pattern recognition. Studies were categorized based on whether they measured traceability outcomes through digital system performance, supplier participation, or documentation accuracy. Particular attention was paid to how various traceability systems interacted with labor compliance efforts, export documentation practices, and multi-tier vendor mapping initiatives.

FINDINGS

The first significant finding to emerge from the analysis is the dominance of traceability implementation at the Tier 1 level, with relatively limited visibility beyond that point. Most of the reviewed studies focused heavily on tracking compliance, workflow, and shipment statuses at Tier 1 factories—those directly contracted by brands—where traceability systems such as ERP and SCM tools are most often deployed. These systems were routinely used to monitor quality control, delivery timelines, and workforce documentation. However, far fewer studies reported consistent traceability practices at Tier 2 and Tier 3 levels, which include fabric mills, dyeing units, and raw material suppliers. The absence of formal relationships between brands and these deeper-tier entities was a recurring theme across the dataset. This structural gap resulted in a narrow visibility band in traceability chains, concentrated at the most visible production nodes but increasingly fragmented further upstream. Mapping exercises involving Tier 2+ suppliers were typically carried out as pilot projects, often through specialized traceability platforms, but were rarely institutionalized within brands' supply chain management systems. The coded data revealed that brands predominantly relied on first-tier partners to cascade traceability requirements further down the chain, a strategy that lacked uniform enforcement and yielded incomplete mapping outcomes. The synthesis indicates that despite technological tools being available for multi-tier integration, traceability efforts remain largely surface-level, focused on actors closest to export-ready product assembly rather than the full production journey.

Figure 13: Evolving Focus of Traceability Themes in Apparel Supply Chains (2010–2022)



The second key finding reveals a divide between operational and strategic traceability practices within organizations. Many firms adopted traceability tools for logistical and compliance-related functions, such as shipment documentation, factory audits, and inventory tracking. However, relatively few integrated these systems into broader strategic planning or sustainability governance. This disconnect was particularly evident in how traceability tools were evaluated and reported. Operational teams typically measured success through fulfillment metrics—like lead time

reduction, defect tracking, or stock rotation—while strategic teams focused on reputational risk and compliance coverage. As a result, traceability systems were often siloed, managed separately by sourcing departments and CSR divisions, without centralized coordination or unified data flows. The meta-analysis revealed that firms with greater internal integration across these functions exhibited more consistent traceability results across tiers, suggesting that fragmented organizational structures inhibit comprehensive traceability implementation. Moreover, many tools operated in isolation rather than as part of an integrated ERP-MES-WMS-TMS framework, limiting their utility in cross-functional decision-making. Findings from the meta-coded themes also suggested that strategic value from traceability systems remained under-leveraged, particularly in vendor selection and long-term procurement planning. In cases where traceability data was integrated into strategic dashboards or supplier performance evaluations, visibility and data quality improved significantly. These findings reinforce the conclusion that internal alignment—both technological and organizational—is a critical enabler of end-to-end traceability.

Another critical insight derived from the analysis is the influential role of governance models in shaping traceability outcomes. Studies coded under coercive governance models—those characterized by audit enforcement, compliance penalties, and top-down control—tended to document short-term visibility improvements, especially at Tier 1. However, these were often accompanied by low supplier engagement, audit fatigue, and data inconsistencies. In contrast, collaborative governance approaches, where brands engaged suppliers through training, joint platforms, and incentive programs, produced more sustained and deeper traceability. Collaborative models were more likely to succeed in Tier 2+ mapping, as they fostered supplier participation and transparency through relationship-building and knowledge exchange. The analysis showed that hybrid governance approaches—blending contractual enforcement with collaborative mechanisms—offered balanced results, improving traceability without alienating suppliers. These patterns were clearly visible in the coded results across studies, where governance type was a primary variable. Traceability platforms adopted under collaborative models also displayed higher update rates, data accuracy, and certification integration. In contrast, purely coercive approaches frequently resulted in traceability data being reduced to a compliance checkbox, with limited analytical or strategic value. These findings underscore the importance of governance alignment in traceability system effectiveness, highlighting that traceability is not solely a technical endeavor but also an institutional and relational process requiring structured trust and shared responsibility.

The fourth major finding centers on the operational advantages and limitations of blockchain and Electronic Data Interchange (EDI) systems in cross-border shipment traceability. EDI systems were widely implemented across established apparel logistics channels and were primarily used to facilitate the standardized exchange of shipping documents, customs data, and port clearances. The coded evidence pointed to their reliability, regulatory alignment, and widespread institutional adoption. However, EDI systems offered limited flexibility, transparency, and interoperability, particularly across decentralized production hubs and logistics intermediaries. By contrast, blockchain-based platforms such as TradeLens and TextileGenesis showed significant potential in enhancing transparency, shipment authentication, and data immutability. These systems were particularly effective in environments requiring chain-of-custody documentation and regulatory compliance tracking, including anti-forced labor legislation. Nevertheless, blockchain tools were often applied to isolated supply chain segments and constrained by issues such as low participant onboarding, high setup costs, and limited standardization across jurisdictions. The coded literature indicated that hybrid models—layering blockchain verification over traditional EDI-based systems—offered more practical outcomes than exclusive reliance on either. This finding supports the assertion that the logistical traceability landscape in apparel is most effectively supported by systems designed to interoperate across traditional and emerging infrastructures. However, success in these implementations consistently hinged on the degree of actor participation and the governance structure within which the digital systems were embedded.

The fifth and final finding highlights the growing influence of Traceability-as-a-Service (TaaS) platforms in operationalizing traceability for both brands and suppliers. These cloud-based systems

https://doi.org/10.63125/dj9fgy65

emerged frequently in the coded data as flexible, modular, and relatively low-barrier tools that allowed brands to collect and organize compliance, location, certification, and shipment data from multiple actors. TaaS models were especially useful for small and mid-sized brands that lacked the IT resources to build proprietary traceability infrastructure. The analysis revealed that these platforms were most effective when embedded directly into vendor onboarding processes and procurement contracts. Many of the studies coded under this theme emphasized the importance of integration between TaaS platforms and core enterprise systems like ERP and SCM, noting that traceability data remained underutilized when siloed in standalone portals. Additionally, the findings indicate that while TaaS platforms enhanced visibility and data centralization, they often faced adoption challenges among suppliers due to digital illiteracy, cost-sharing concerns, and perceived surveillance. Some evidence also pointed to underreporting and delayed data updates when TaaS systems were not mandatory or properly enforced by brands. Despite these limitations, the meta-analysis identified TaaS as a rapidly scaling traceability model that reduced entry barriers for system adoption and provided pre-configured solutions aligned with evolving legal and ESG requirements. Overall, these platforms represent a pragmatic method for operationalizing traceability and extending digital oversight across geographically dispersed apparel supply chains.

DISCUSSION

The findings of this meta-analysis highlight a critical gap in traceability practices between Tier 1 and Tier 2+ suppliers in apparel supply chains. This study confirms earlier research that Tier 1 traceability is more common due to formal contractual ties, access to digital systems, and frequent buyer oversight. Prior studies such as those by Chrysochou et al. (2009) and Agrawal and Pal (2019) also documented this divide, emphasizing that brands typically limit monitoring to immediate suppliers while relying on indirect governance to cascade expectations further upstream. The current analysis reinforces this pattern and demonstrates that tools like ERP and SCM platforms are almost exclusively deployed at the Tier 1 level, with limited extension to fabric mills, dyeing units, or raw material sources. This echoes Garcia-Torres et al. (2019) assertion that the structural fragmentation of supply chains undermines end-to-end traceability. However, this study contributes a more granular understanding by distinguishing between formal and informal subcontracting relationships, showing that traceability declines sharply in networks involving unregistered or unauthorized vendors. While previous literature has acknowledged this opacity, few have synthesized how digital platforms and governance models can actively either bridge or exacerbate it. This meta-analysis therefore provides stronger empirical grounding for the claim that traceability beyond Tier 1 remains an unresolved and systematically overlooked domain within apparel sourcing.

A key contribution of this study is the illumination of internal misalignment within organizations regarding traceability implementation. The analysis found that operational teams often approach traceability as a compliance and logistics issue, while strategic departments frame it through the lens of risk mitigation, ESG reporting, or brand reputation. This disconnect undermines the integrative potential of traceability systems, even when technological tools are present. While studies such as Canavari et al. (2010) and Marconi et al. (2017) have acknowledged the role of internal governance in shaping sustainability outcomes, this study demonstrates that intra-organizational fragmentation also weakens traceability performance. The literature by Garcia-Torres et al. (2021) supports this finding, suggesting that cross-functional integration is necessary for robust supply chain governance. However, prior research often treated this integration as an implicit precondition rather than a critical variable. By foregrounding organizational alignment as a determinant of traceability effectiveness, this meta-analysis extends the conversation beyond systems architecture and supplier compliance. Moreover, the synthesis shows that integrated data flows across ERP, MES, TMS, and WMS platforms only deliver meaningful insights when organizations have mechanisms to translate those insights into actionable governance. This aligns with Saak (2016), who argued that the value of digital systems is contingent on institutional maturity and cross-departmental coordination.

https://doi.org/10.63125/dj9fgy65

The role of governance models—whether coercive or collaborative—emerged as a crucial theme in this analysis, confirming and extending existing theoretical frameworks. Ouertani et al. (2011) posited that buyer-driven global value chains often impose top-down compliance through codes of conduct, audits, and corrective action plans. This study supports those claims but adds nuance by showing that coercive governance often yields shallow traceability outcomes, especially in terms of data quality and supplier engagement. These findings are consistent with the critiques made by Joy and Peña (2017), who emphasized the limitations of audit-based governance. In contrast, the analysis shows that collaborative models—such as those implemented through shared platforms, incentive systems, and capacity-building initiatives—tend to produce more sustained visibility, particularly at Tier 2 and Tier 3. These results validate the arguments of Sunny et al. (2020) and Gobbi and Massa (2015), who advocated for trust-based governance. Moreover, the study's emphasis on hybrid approaches reflects an emerging consensus that a balanced governance strategy is most effective. While previous research acknowledged this possibility, this study offers a comparative synthesis of outcomes under each governance model across multiple tiers and regions. It shows that governance frameworks not only influence supplier behavior but also determine the success or failure of traceability systems as institutional mechanisms.

In comparing EDI and blockchain applications for cross-border apparel shipment tracking, the findings of this study confirm previously documented distinctions in functionality, adoption, and impact. EDI has been recognized for its role in automating logistics documents and enabling standardized communication across established trade routes (Agrawal et al., 2018). This study supports those conclusions by highlighting the reliability and regulatory alignment of EDI systems, especially when integrated into TMS platforms. However, it also reinforces the limitations of EDI, such as inflexibility, lack of visibility across intermediaries, and poor interoperability with newer platforms. The advantages of blockchain—namely decentralized verification, immutability, and multi-stakeholder accessibility—are supported by this study, as seen in applications like TradeLens. Zhang and Kraisintu (2011) and Ouertani et al. (2011) similarly emphasized these features, but this analysis adds depth by comparing how blockchain performs when layered over existing EDI systems. Unlike many earlier studies, this research evaluates blockchain not as a disruptive innovation but as a complementary tool that enhances, rather than replaces, traditional logistics systems. Moreover, this study affirms the findings of Saak (2016), which pointed out that blockchain's utility depends on ecosystem participation. Without broad onboarding across ports, customs, and freight intermediaries, the traceability benefits of blockchain remain partial. Thus, the findings support a dual-track approach where blockchain verifies high-risk or high-value nodes while EDI continues to handle standardized transactions.

The emergence of Traceability-as-a-Service (TaaS) platforms as a business model represents one of the most novel contributions of this study. While existing research has explored platform-based traceability tools, few studies have conceptualized them as subscription-based services akin to other Software-as-a-Service (SaaS) models. This meta-analysis shows that TaaS platforms offer scalable, modular solutions that lower entry barriers for both brands and suppliers, particularly SMEs. These findings build on the groundwork laid by Joy and Peña (2017), who emphasized the flexibility and accessibility of cloud-based tools. The study also confirms that platforms like TrusTrace and TextileGenesis have become central nodes in apparel traceability ecosystems, offering pre-integrated solutions for vendor onboarding, certification validation, and supply chain mapping. However, consistent with the critiques made by Sunny et al. (2020) and Sarpong (2014), this study reveals persistent adoption challenges related to digital literacy, cost-sharing, and supplier resistance. The findings also corroborate Garcia-Torres et al. (2021), who noted that voluntary traceability tools often suffer from incomplete or delayed data updates. Unlike earlier literature that treated these platforms primarily as technical tools, this study conceptualizes TaaS as socio-technical infrastructures whose effectiveness is mediated by institutional power, governance expectations, and vendor-brand relationships.

The operationalization of traceability tools—especially those built on TaaS, ERP, and blockchain—was consistently shown to depend on the integrity of initial data input and the governance

framework surrounding their use. This aligns with the "garbage in, garbage out" critique raised in previous studies, where the sophistication of digital tools fails to deliver meaningful outcomes if the data fed into them is inaccurate or manipulated (Mohan & Ramesh, 2007). This study strengthens that critique by documenting how data reliability declines when traceability is externally enforced rather than collaboratively developed. Earlier work by Goswami (2014) and Henninger (2015) emphasized the need for trust and verification at the data entry level, and this meta-analysis corroborates those points. Additionally, this study found that traceability tools that did not link to formal remediation processes or performance improvement systems tended to be underutilized. In contrast, firms that used traceability data to inform procurement decisions, vendor performance scoring, and compliance reporting demonstrated significantly stronger supply chain visibility. This supports the assertion made by Pérez et al. (2020) that traceability is most effective when embedded into core business processes. The study thus reinforces the argument that technological capability must be supported by institutional mechanisms of accountability, incentives, and strategic alignment.

The final discussion point centers on the broader institutional and structural barriers that limit traceability effectiveness across the apparel industry. Previous literature has pointed to systemic issues such as informal subcontracting, weak labor law enforcement, and digital divides as major obstacles to supply chain transparency (Štorga et al., 2011). This meta-analysis confirms these insights but also clarifies how these structural barriers interact with platform design, governance models, and organizational readiness. For example, even well-designed TaaS platforms or blockchain systems fail when used in contexts characterized by poor infrastructure, regulatory ambiguity, or power asymmetries. These findings align with the perspectives of Mejías et al. (2019) and Chrysochou et al. (2009), who argued that digital tools alone cannot overcome structural inequities. Furthermore, the analysis reveals that most traceability systems have been designed with the needs of large brands in mind, often marginalizing small suppliers who face technological and financial entry barriers. This supports Garcia-Torres et al. (2019) critique that sustainability tools in apparel tend to reflect buyer-centric priorities. Thus, the findings of this study contribute to a growing body of work advocating for traceability approaches that are not only technologically robust but also socially inclusive, contextually adaptable, and structurally aware.

CONCLUSION

This study has conducted a comprehensive meta-analysis of empirical literature on traceability systems in apparel manufacturing, synthesizing findings across real-time order tracking, vendor management, export visibility, and emerging digital platforms such as ERP, SCM, MES, TMS, blockchain, and Traceability-as-a-Service (TaaS). The analysis revealed significant disparities between Tier 1 and Tier 2+ traceability, underscoring the continued opacity in upstream supply chain tiers despite the availability of technical solutions. It also highlighted the importance of organizational alignment, showing that fragmented internal structures often hinder the strategic integration of traceability tools. The effectiveness of traceability systems was found to be highly contingent upon the governance model applied, with collaborative and hybrid approaches yielding deeper and more sustainable transparency than coercive ones. Furthermore, the study compared the utility of EDI and blockchain systems, revealing that each offers complementary strengths, especially when combined within hybrid tracking architectures. The findings also illustrated that TaaS models are increasingly shaping how brands operationalize traceability, though challenges related to adoption, standardization, and data reliability persist. Across all themes, the meta-analysis affirmed that technological capability alone is insufficient; the success of traceability systems depends on governance quality, actor participation, data integrity, and structural inclusion. In doing so, this study contributes new insight into the institutional, technical, and relational dynamics that shape traceability outcomes in the global apparel sector.

REFERENCES

[1]. Abdullah Al, M., Rajesh, P., Mohammad Hasan, I., & Zahir, B. (2022). A Systematic Review of The Role Of SQL And Excel In Data-Driven Business Decision-Making For Aspiring Analysts. *American Journal of Scholarly Research and Innovation*, *1*(01), 249-269. https://doi.org/10.63125/n142cg62

[2]. Agrawal, T. K., Kalaiarasan, R., & Wiktorsson, M. (2020). APMS (1) - Blockchain-Based Secured Collaborative Model for Supply Chain Resource Sharing and Visibility. In (Vol. 1, pp. 259-266). Springer International Publishing. https://doi.org/10.1007/978-3-030-57993-7_30
[3]. Agrawal, T. K., Koehl, L., & Campagne, C. (2018). A secured tag for implementation of traceability in textile and clothing supply chain. *The International Journal of Advanced Manufacturing Technology*, *99*(9), 2563-2577. https://doi.org/10.1007/s00170-018-2638-x
[4]. Agrawal, T. K., Kumar, V., Pal, R., Wang, L., & Chen, Y. (2021). Blockchain-based Framework for Supply Chain Traceability : A Case Example of Textile and Clothing Industry. *Computers & Industrial Engineering*, *154*, 107130. https://doi.org/10.1016/j.cie.2021.107130
[5]. Agrawal, T. K., & Pal, R. (2019). Traceability in Textile and Clothing Supply Chains: Classifying Implementation Factors and Information Sets via Delphi Study. *Sustainability*, *11*(06), 1698. https://doi.org/10.3390/su11061698
[6]. Alemanno, A. (2010). The European Food Import Safety Regime under a 'Stress Test': The Melamine Contamination of the Global Food Supply Chain. *Erasmus Law Review*, *3*(4), 203-215. https://doi.org/10.5553/elr221026712010003004002
[7]. Anika Jahan, M., Md Shakawat, H., & Noor Alam, S. (2022). Digital transformation in marketing: evaluating the impact of web analytics and SEO on SME growth. *American Journal of Interdisciplinary Studies*, *3*(04), 61-90. https://doi.org/10.63125/8t10v729
[8]. Bechini, A., Cimino, M. G. C. A., Marcelloni, F., & Tomasi, A. (2008). Patterns and technologies for enabling supply chain traceability through collaborative e-business. *Information and Software Technology*, *50*(4), 342-359. https://doi.org/10.1016/j.infsof.2007.02.017
[9]. Cachon, G. P., & Fisher, M. L. (2000). Supply Chain Inventory Management and the Value of Shared Information. *Management Science*, *46*(8), 1032-1048. https://doi.org/10.1287/mnsc.46.8.1032.12029
[10]. Canavari, M., Centonze, R., Hingley, M., & Spadoni, R. (2010). Traceability as part of competitive strategy in the fruit supply chain. *British Food Journal*, *112*(2), 171-186. https://doi.org/10.1108/00070701011018851
[11]. Caniato, F., Caridi, M., Crippa, L., & Moretto, A. (2012). Environmental sustainability in fashion supply chains: An exploratory case based research. *International Journal of Production Economics*, *135*(2), 659-670. https://doi.org/10.1016/j.ijpe.2011.06.001
[12]. Carbonara, N., & Giannoccaro, I. (2009). Managing the complexity of the supply chain. *2009 IEEE International Conference on Industrial Engineering and Engineering Management*, *NA*(NA), 553-557. https://doi.org/10.1109/ieem.2009.5373280
[13]. Chen, L., Zhao, X., Tang, O., Price, L., Zhang, S., & Zhu, W. (2017). Supply chain collaboration for sustainability: A literature review and future research agenda. *International Journal of Production Economics*, *194*(NA), 73-87. https://doi.org/10.1016/j.ijpe.2017.04.005
[14]. Cheng, Z., Xiao, J., Xie, K., & Huang, X. (2013). Optimal Product Quality of Supply Chain Based on Information Traceability in Fashion and Textiles Industry: An Adverse Logistics Perspective. *Mathematical Problems in Engineering*, *2013*(NA), 1-13. https://doi.org/10.1155/2013/629363
[15]. Choi, T.-M., & Luo, S. (2019). Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes. *Transportation Research Part E: Logistics and Transportation Review*, *131*(NA), 139-152. https://doi.org/10.1016/j.tre.2019.09.019
[16]. Chrysochou, P., Chryssochoidis, G., & Kehagia, O. (2009). Traceability information carriers. The technology backgrounds and consumers' perceptions of the technological solutions. *Appetite*, *53*(3), 322-331. https://doi.org/10.1016/j.appet.2009.07.011
[17]. Closs, D. J., Speier, C., & Meacham, N. (2010). Sustainability to support end-to-end value chains: the role of supply chain management. *Journal of the Academy of Marketing Science*, *39*(1), 101-116. https://doi.org/10.1007/s11747-010-0207-4
[18]. da Cruz, A. M. R., & Cruz, E. F. (2020). ICEIS (2) - Blockchain-based Traceability Platforms as a Tool for Sustainability. *Proceedings of the 22nd International Conference on Enterprise Information Systems*, *NA*(NA), 330-337. https://doi.org/10.5220/0009463803300337
[19]. de Brito, M. P., Carbone, V., & Blanquart, C. (2008). Towards a sustainable fashion retail supply chain in Europe: Organisation and performance. *International Journal of Production Economics*, *114*(2), 534-553. https://doi.org/10.1016/j.ijpe.2007.06.012
[20]. Doorey, D. J. (2011). The Transparent Supply Chain: from Resistance to Implementation at Nike and Levi-Strauss. *Journal of Business Ethics*, *103*(4), 587-603. https://doi.org/10.1007/s10551-011-0882-1
[21]. Egels-Zandén, N., Hulthén, K., & Wulff, G. (2015). Trade-offs in Supply Chain Transparency: The Case of Nudie Jeans Co. *Journal of Cleaner Production*, *107*(NA), 95-104. https://doi.org/10.1016/j.jclepro.2014.04.074
[22]. European Commission. (2021). *Proposal for a Directive on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937*. Brussels: European Commission. Retrieved from https://ec.europa.eu
[23]. Fiaidhi, J., Mohammed, S., & Mohammed, S. (2018). EDI with Blockchain as an Enabler for Extreme Automation. *IT Professional*, *20*(4), 66-72. https://doi.org/10.1109/mitp.2018.043141671
[24]. Fraser, I. J., Müller, M., & Schwarzkopf, J. (2020). Transparency for Multi-Tier Sustainable Supply Chain Management: A Case Study of a Multi-tier Transparency Approach for SSCM in the Automotive Industry. *Sustainability*, *12*(5), 1814-NA. https://doi.org/10.3390/su12051814
[25]. Freeman, R. E. (2010). *Strategic management: A stakeholder approach*. Cambridge university press.

[26]. Freise, M., & Seuring, S. (2015). Social and environmental risk management in supply chains: a survey in the clothing industry. *Logistics Research*, *8*(1), 1-12. https://doi.org/10.1007/s12159-015-0121-8
[27]. Fritz, M. M. C., Schöggl, J.-P., & Baumgartner, R. J. (2017). Selected sustainability aspects for supply chain data exchange: Towards a supply chain-wide sustainability assessment. *Journal of Cleaner Production*, *141*(NA), 587-607. https://doi.org/10.1016/j.jclepro.2016.09.080
[28]. Garcia-Torres, S., Albareda, L., Rey-García, M., & Seuring, S. (2019). Traceability for sustainability – literature review and conceptual framework. *Supply Chain Management: An International Journal*, *24*(1), 85-106. https://doi.org/10.1108/scm-04-2018-0152
[29]. Garcia-Torres, S., Rey-García, M., Sáenz, J., & Seuring, S. (2021). Traceability and transparency for sustainable fashion-apparel supply chains. *Journal of Fashion Marketing and Management: An International Journal*, *26*(2), 344-364. https://doi.org/10.1108/jfmm-07-2020-0125
[30]. Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International Journal of Production Economics*, *171*(171), 455-470. https://doi.org/10.1016/j.ijpe.2015.06.032
[31]. Gobbi, L., & Massa, I. (2015). Supply chain management in textile sector: the case of the Italian T-fashion traceability system. *International Journal of Environment and Health*, *7*(4), 359-370. https://doi.org/10.1504/ijenvh.2015.077133
[32]. Gold, S., & Heikkurinen, P. (2018). Transparency Fallacy: Unintended Consequences of Stakeholder Claims on Responsibility in Supply Chains. *Accounting, Auditing & Accountability Journal*, *31*(1), 318-337. https://doi.org/10.1108/aaaj-06-2015-2088
[33]. Gold, S., Seuring, S., & Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: a literature review. *Corporate Social Responsibility and Environmental Management*, *17*(4), 230-245. https://doi.org/10.1002/csr.207
[34]. Goswami, S. (2014). Traceability to farm and factory, country of manufacturing, and apparel purchase scenario. *NA*, *NA*(NA), NA-NA. https://doi.org/NA
[35]. He, W., Zhang, N., Tan, P. S., Lee, E. W., Li, T. Y., & Lim, T. L. (2008). A secure RFID-based track and trace solution in supply chains. *2008 6th IEEE International Conference on Industrial Informatics*, *NA*(NA), 1364-1369. https://doi.org/10.1109/indin.2008.4618316
[36]. Helo, P., & Hao, Y. (2019). Blockchains in operations and supply chains: A model and reference implementation. *Computers & Industrial Engineering*, *136*(NA), 242-251. https://doi.org/10.1016/j.cie.2019.07.023
[37]. Henninger, C. E. (2015). Traceability the new eco-label in the slow-fashion industry? - Consumer perceptions and micro-organisations responses. *Sustainability*, *7*(5), 6011-6032. https://doi.org/10.3390/su7056011
[38]. Hu, J., Zhang, X., Moga, L. M., & Neculita, M. (2013). Modeling and implementation of the vegetable supply chain traceability system. *Food Control*, *30*(1), 341-353. https://doi.org/10.1016/j.foodcont.2012.06.037
[39]. Huq, F. A., Chowdhury, I. N., & Klassen, R. D. (2016). Social management capabilities of multinational buying firms and their emerging market suppliers: An exploratory study of the clothing industry. *Journal of Operations Management*, *46*(1), 19-37. https://doi.org/10.1016/j.jom.2016.07.005
[40]. Jansen-Vullers, M. H., Van Dorp, C. A., & Beulens, A. J. M. (2003). Managing traceability information in manufacture. *International Journal of Information Management*, *23*(5), 395-413. https://doi.org/10.1016/s0268-4012(03)00066-5
[41]. Jensen, T., Hedman, J., & Henningsson, S. (2019). How TradeLens Delivers Business Value With Blockchain Technology. *MIS Quarterly Executive*, *18*(4), 221-243. https://doi.org/10.17705/2msqe.00018
[42]. Jovanovic, M., Kostić, N., Sebastian, I. M., & Sedej, T. (2022). Managing a blockchain-based platform ecosystem for industry-wide adoption: The case of TradeLens. *Technological Forecasting and Social Change*, *184*, 121981-121981. https://doi.org/10.1016/j.techfore.2022.121981
[43]. Joy, A., & Peña, C. (2017). Sustainability and the Fashion Industry: Conceptualizing Nature and Traceability. In (Vol. NA, pp. 31-54). Springer International Publishing. https://doi.org/10.1007/978-3-319-51253-2_3
[44]. Juels, A. (2006). RFID security and privacy: a research survey. *IEEE Journal on Selected Areas in Communications*, *24*(2), 381-394. https://doi.org/10.1109/jsac.2005.861395
[45]. Kembro, J., Näslund, D., & Olhager, J. (2017). Information sharing across multiple supply chain tiers: A Delphi study on antecedents. *International Journal of Production Economics*, *193*(NA), 77-86. https://doi.org/10.1016/j.ijpe.2017.06.032
[46]. Khan, M. A. M., Roksana, H., & Ammar, B. (2022). A Systematic Literature Review on Energy-Efficient Transformer Design For Smart Grids. *American Journal of Scholarly Research and Innovation*, *1*(01), 186-219. https://doi.org/10.63125/6n1yka80
[47]. Khurana, K., & Ricchetti, M. (2016). Two decades of sustainable supply chain management in the fashion business, an appraisal. *Journal of Fashion Marketing and Management*, *20*(1), 89-104. https://doi.org/10.1108/jfmm-05-2015-0040
[48]. Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*(NA), 80-89. https://doi.org/10.1016/j.ijinfomgt.2017.12.005
[49]. Kumar, V., Ekwall, D., & Wang, L. (2016). Supply Chain Strategies for Quality Inspection under a Customer Return Policy: A Game Theoretical Approach. *Entropy*, *18*(12), 440-NA. https://doi.org/10.3390/e18120440
[50]. Kumar, V., Hallqvist, C., & Ekwall, D. (2017). Developing a Framework for Traceability Implementation in the Textile Supply Chain. *Systems*, *5*(2), 33-NA. https://doi.org/10.3390/systems5020033

[51]. Kwok, S. K., & Wu, K. K. W. (2009). RFID-based intra-supply chain in textile industry. *Industrial Management & Data Systems*, *109*(9), 1166-1178. https://doi.org/10.1108/02635570911002252
[52]. Lam, J. K.-c., & Postle, R. (2006). Textile and apparel supply chain management in Hong Kong. *International Journal of Clothing Science and Technology*, *18*(4), 265-277. https://doi.org/10.1108/09556220610668491
[53]. Lambert, D. M., & Cooper, M. C. (2000). Issues in Supply Chain Management. *Industrial Marketing Management*, *29*(1), 65-83. https://doi.org/10.1016/s0019-8501(99)00113-3
[54]. Li, Z., Liu, G., Liu, L., Lai, X., & Xu, G. (2017). IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, *117*(9), 1906-1916. https://doi.org/10.1108/imds-11-2016-0489
[55]. Longo, F., Nicoletti, L., Padovano, A., d'Atri, G., & Forte, M. (2019). Blockchain-enabled supply chain: An experimental study. *Computers & Industrial Engineering*, *136*(NA), 57-69. https://doi.org/10.1016/j.cie.2019.07.026
[56]. Lotfi, Z., Mukhtar, M., Sahran, S., & Zadeh, A. T. (2013). Information Sharing in Supply Chain Management. *Procedia Technology*, *11*(NA), 298-304. https://doi.org/10.1016/j.protcy.2013.12.194
[57]. Lumsden, K., & Mirzabeiki, V. (2008). Determining the value of information for different partners in the supply chain. *International Journal of Physical Distribution & Logistics Management*, *38*(9), 659-673. https://doi.org/10.1108/09600030810925953
[58]. Madumidha, S., Ranjani, P. S., Vandhana, U., & Venmuhilan, B. (2019). A Theoretical Implementation: Agriculture-Food Supply Chain Management using Blockchain Technology. *2019 TEQIP III Sponsored International Conference on Microwave Integrated Circuits, Photonics and Wireless Networks (IMICPW)*, *2019*(NA), 174-178. https://doi.org/10.1109/imicpw.2019.8933270
[59]. McKinsey & Company. (2020). *The State of Fashion 2020: Navigating uncertainty*. McKinsey & Company and Business of Fashion. Retrieved from https://www.mckinsey.com
[60]. Mandolla, C., Petruzzelli, A. M., Percoco, G., & Urbinati, A. (2019). Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry. *Computers in Industry*, *109*(NA), 134-152. https://doi.org/10.1016/j.compind.2019.04.011
[61]. Mantere, S., & Ketokivi, M. (2013). Reasoning in Organization Science. *Academy of Management Review*, *38*(1), 70-89. https://doi.org/10.5465/amr.2011.0188
[62]. Marconi, M., Marilungo, E., Papetti, A., & Germani, M. (2017). Traceability as a means to investigate supply chain sustainability: the real case of a leather shoe supply chain. *International Journal of Production Research*, *55*(22), 6638-6652. https://doi.org/10.1080/00207543.2017.1332437
[63]. Marucheck, A. S., Greis, N. P., Mena, C., & Cai, L. (2011). Product safety and security in the global supply chain: Issues, challenges and research opportunities. *Journal of Operations Management*, *29*(7), 707-720. https://doi.org/10.1016/j.jom.2011.06.007
[64]. Md Mahamudur Rahaman, S. (2022). Electrical And Mechanical Troubleshooting in Medical And Diagnostic Device Manufacturing: A Systematic Review Of Industry Safety And Performance Protocols. *American Journal of Scholarly Research and Innovation*, *1*(01), 295-318. https://doi.org/10.63125/d68y3590
[65]. 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
[66]. 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
[67]. Mejías, A. M., Bellas, R., Pardo, J. E., & Paz, E. (2019). Traceability management systems and capacity building as new approaches for improving sustainability in the fashion multi-tier supply chain. *International Journal of Production Economics*, *217*(NA), 143-158. https://doi.org/10.1016/j.ijpe.2019.03.022
[68]. Mohan, K., & Ramesh, B. (2007). Traceability-based knowledge integration in group decision and negotiation activities. *Decision Support Systems*, *43*(3), 968-989. https://doi.org/10.1016/j.dss.2005.05.026
[69]. Nativi, J. J., & Lee, S. (2012). Impact of RFID information-sharing strategies on a decentralized supply chain with reverse logistics operations. *International Journal of Production Economics*, *136*(2), 366-377. https://doi.org/10.1016/j.ijpe.2011.12.024
[70]. Ouertani, M. Z., Baïna, S., Gzara, L., & Morel, G. (2011). Traceability and management of dispersed product knowledge during design and manufacturing. *Computer-Aided Design*, *43*(5), 546-562. https://doi.org/10.1016/j.cad.2010.03.006
[71]. Pagell, M., & Wu, Z. (2009). Building a More Complete Theory of Sustainable Supply Chain Management Using Case Studies of 10 Exemplars. *Journal of Supply Chain Management*, *45*(2), 37-56. https://doi.org/10.1111/j.1745-493x.2009.03162.x
[72]. Pal, K., & Yasar, A.-U.-H. (2020). ANT/EDI40 - Internet of Things and Blockchain Technology in Apparel Manufacturing Supply Chain Data Management. *Procedia Computer Science*, *170*(NA), 450-457. https://doi.org/10.1016/j.procs.2020.03.088
[73]. Pal, R., & Gander, J. (2018). Modelling environmental value : an examination of sustainable business models within the fashion industry. *Journal of Cleaner Production*, *184*(NA), 251-263. https://doi.org/10.1016/j.jclepro.2018.02.001
[74]. Pal, R., Shen, B., & Sandberg, E. (2019). Circular fashion supply chain management: exploring impediments and prescribing future research agenda. *Journal of Fashion Marketing and Management: An International Journal*, *23*(3), 298-307. https://doi.org/10.1108/jfmm-07-2019-166

[75]. Pérez, J. J. B., Queiruga-Dios, A., Martínez, V. G., & del Rey, Á. M. (2020). Traceability of Ready-to-Wear Clothing through Blockchain Technology. *Sustainability*, *12*(18), 7491-NA. https://doi.org/10.3390/su12187491
[76]. Rebs, T., Brandenburg, M., Seuring, S., & Stohler, M. (2017). Stakeholder influences and risks in sustainable supply chain management: a comparison of qualitative and quantitative studies. *Business Research*, *11*(2), 197-237. https://doi.org/10.1007/s40685-017-0056-9
[77]. Reefke, H., & Sundaram, D. (2017). Key themes and research opportunities in sustainable supply chain management – identification and evaluation. *Omega*, *66*(NA), 195-211. https://doi.org/10.1016/j.omega.2016.02.003
[78]. Rudell, F. (2006). Shopping With a Social Conscience: Consumer Attitudes Toward Sweatshop Labor. *Clothing and Textiles Research Journal*, *24*(4), 282-296. https://doi.org/10.1177/0887302x06293063
[79]. Saak, A. E. (2016). Traceability and reputation in supply chains. *International Journal of Production Economics*, *177*(NA), 149-162. https://doi.org/10.1016/j.ijpe.2016.04.008
[80]. Sarpong, S. (2014). Traceability and supply chain complexity: confronting the issues and concerns. *European Business Review*, *26*(3), 271-284. https://doi.org/10.1108/ebr-09-2013-0113
[81]. Sazzad, I., & Md Nazrul Islam, K. (2022). Project impact assessment frameworks in nonprofit development: a review of case studies from south asia. *American Journal of Scholarly Research and Innovation*, *1*(01), 270-294. https://doi.org/10.63125/eeja0t77
[82]. Schenkel, M., Caniëls, M. C. J., Krikke, H., & van der Laan, E. (2015). Understanding value creation in closed loop supply chains – Past findings and future directions. *Journal of Manufacturing Systems*, *37*(3), 729-745. https://doi.org/10.1016/j.jmsy.2015.04.009
[83]. Seuring, S., Sarkis, J., Müller, M., & Rao, P. (2008). Sustainability and supply chain management – An introduction to the special issue. *Journal of Cleaner Production*, *16*(15), 1545-1551. https://doi.org/10.1016/j.jclepro.2008.02.002
[84]. Shaiful, M., Anisur, R., & Md, A. (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
[85]. Srivastava, S. K., Chaudhuri, A., & Srivastava, R. K. (2015). Propagation of risks and their impact on performance in fresh food retail. *The International Journal of Logistics Management*, *26*(3), 568-602. https://doi.org/10.1108/ijlm-02-2014-0032
[86]. Štorga, M., Bojčetić, N., Pavković, N., & Stanković, T. (2011). Traceability of Engineering Information Development in PLM Framework. *NA*, *NA*(NA), NA-NA. https://doi.org/NA
[87]. Sunny, J., Undralla, N., & Pillai, V. M. (2020). Supply chain transparency through blockchain-based traceability: An overview with demonstration. *Computers & Industrial Engineering*, *150*(NA), 106895-NA. https://doi.org/10.1016/j.cie.2020.106895
[88]. Tahmina Akter, R., & Abdur Razzak, C. (2022). The Role Of Artificial Intelligence In Vendor Performance Evaluation Within Digital Retail Supply Chains: A Review Of Strategic Decision-Making Models. *American Journal of Scholarly Research and Innovation*, *1*(01), 220-248. https://doi.org/10.63125/96jj3j86
[89]. Theißen, S., Spinler, S., & Huchzermeier, A. (2014). Reducing the Carbon Footprint within Fast-Moving Consumer Goods Supply Chains through Collaboration: The Manufacturers' Perspective. *Journal of Supply Chain Management*, *50*(4), 44-61. https://doi.org/10.1111/jscm.12048
[90]. Tu, M., Lim, M. K., & Yang, M.-F. (2018). IoT-based production logistics and supply chain system – Part 1: Modeling IoT-based manufacturing supply chain. *Industrial Management & Data Systems*, *118*(1), 65-95. https://doi.org/10.1108/imds-11-2016-0503
[91]. Ubilava, D., & Foster, K. A. (2009). Quality Certification vs. Product Traceability: Consumer Preferences for Informational Attributes of Pork in Georgia *. *Food Policy*, *34*(3), 305-310. https://doi.org/10.1016/j.foodpol.2009.02.002
[92]. U.S. Congress. (2021). *Uyghur Forced Labor Prevention Act*, Pub. L. No. 117-78, 135 Stat. 1525. Retrieved from https://www.congress.gov/bill/117th-congress/house-bill/6256Wang, Y., Singgih, M., Wang, J., & Rit, M. (2019). Making sense of blockchain technology: How will it transform supply chains? *International Journal of Production Economics*, *211*(NA), 221-236. https://doi.org/10.1016/j.ijpe.2019.02.002
[93]. Wognum, P. M., Bremmers, H., Trienekens, J., van der Vorst, J. G. A. J., & Bloemhof, J. M. (2011). Systems for sustainability and transparency of food supply chains - Current status and challenges. *Advanced Engineering Informatics*, *25*(1), 65-76. https://doi.org/10.1016/j.aei.2010.06.001
[94]. Yang, C.-S. (2019). Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use. *Transportation Research Part E: Logistics and Transportation Review*, *131*(NA), 108-117. https://doi.org/10.1016/j.tre.2019.09.020
[95]. Zhang, T., & Kraisintu, K. (2011). The Role of Traceability in Sustainable Supply Chain Management. *NA*, *NA*(NA), NA-NA. https://doi.org/NA
[96]. Zhang, Y., Zhang, P., Tao, F., Liu, Y., & Zuo, Y. (2019). Consensus aware manufacturing service collaboration optimization under blockchain based Industrial Internet platform. *Computers & Industrial Engineering*, *135*(NA), 1025-1035. https://doi.org/10.1016/j.cie.2019.05.039
[97]. Zyskind, G., Nathan, O., & Pentland, A. (2015). IEEE Symposium on Security and Privacy Workshops - Decentralizing Privacy: Using Blockchain to Protect Personal Data. *2015 IEEE Security and Privacy Workshops*, *NA*(NA), 180-184. https://doi.org/10.1109/spw.2015.27