

Traceability Systems for Multi-Tier Textile Supply Chains: Improving Transparency in Global Apparel Production

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Abstract

Global textile supply chains include multiple production stages across different regions, which creates challenges for coordination and monitoring. Limited traceability across these stages results in gaps in visibility and makes verification of material origins and production practices difficult. This study examines traceability systems in multi-tier apparel supply chains, with emphasis on digital documentation frameworks that record supplier transactions, material flows, and production activities. A qualitative analytical approach is used to review documentation practices and traceability mechanisms within international textile production networks. The analysis covers supply chain mapping, documentation structures, and system integration across production tiers. Results indicate that structured traceability records improve visibility, support compliance monitoring, and reduce fragmentation of information among supply chain participants. These systems allow organizations to track production processes with greater consistency and detect irregularities in material sourcing and supplier activities. The study also presents a traceability framework that integrates supplier databases, production records, and digital tracking technologies within a unified system. This framework supports consistent documentation and improves coordination across global apparel supply chains, contributing to transparent and accountable production practices.

Keywords: Supply chain traceability, textile supply chains, apparel production transparency, global sourcing systems, manufacturing documentation.

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I. INTRODUCTION

Global textile and apparel production networks involve numerous interconnected stages distributed across multiple countries. Cotton farming, yarn production, textile weaving, dyeing, garment assembly, logistics, and retail distribution often occur in different geographical regions. These multi-tier structures create complex supply chain systems where transparency becomes difficult to maintain. Apparel brands frequently depend on several layers of subcontractors and suppliers, making it challenging to verify production practices, material origins, and compliance with ethical standards. As global demand for responsible sourcing increases, organizations seek improved mechanisms for tracking materials and production activities throughout textile supply chains. Traceability systems have emerged as an important solution for improving transparency in global apparel production. Traceability refers to the ability to track and verify the movement of materials and products

through every stage of the supply chain. In textile manufacturing, traceability systems capture data regarding fiber sourcing, fabric processing, garment production, and shipment records. Digital documentation platforms, integrated supplier databases, and blockchain based verification mechanisms have been introduced to support traceability in international supply networks. These systems enable manufacturers and retailers to monitor supplier activities and ensure adherence to regulatory standards and sustainability commitments. The complexity of textile production networks often results in fragmented information flows between suppliers. Traditional documentation systems rely heavily on manual records, which may lead to inconsistencies or limited visibility across production tiers. Digital traceability frameworks address this limitation by establishing structured information systems capable of recording supplier transactions, material movements, and production activities in real time. These systems strengthen accountability among supply chain

participants and support verification of responsible sourcing claims. This study investigates traceability systems within multi-tier textile supply chains and evaluates how structured documentation frameworks improve supply chain transparency. The research

proposes a traceability architecture designed to strengthen monitoring capabilities and improve coordination among international apparel production partners.

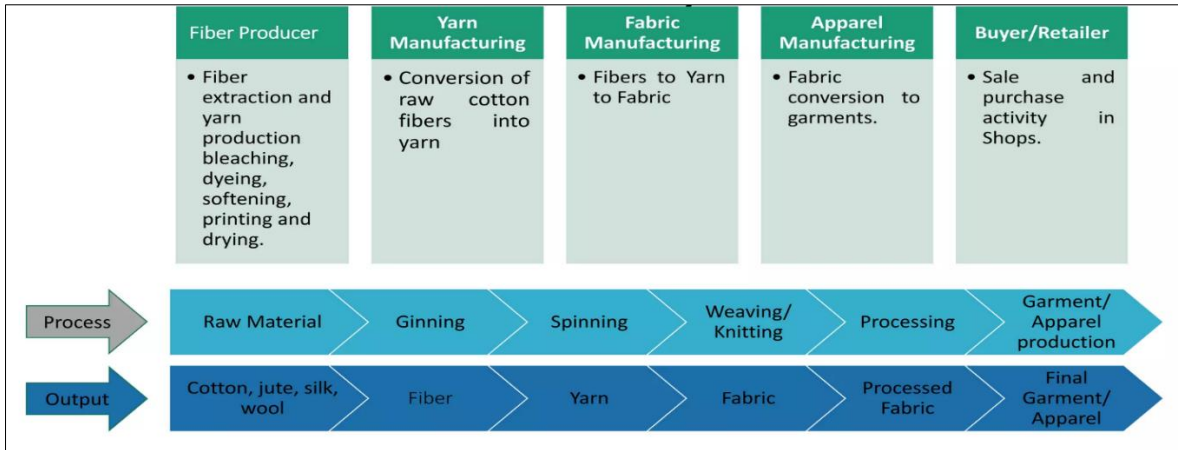


Figure 01: Multi-Tier Structure of Global Textile Supply Chains

1.1 Evolution of Traceability in Textile Production

Traceability in textile production has evolved significantly as global sourcing networks expanded. Earlier apparel supply chains relied primarily on basic procurement records and shipment documentation maintained by individual suppliers. These traditional documentation methods often lacked standardized formats, making it difficult for retailers to track the origins of materials or verify production processes across multiple tiers. As production outsourcing increased, supply chains became geographically dispersed and involved numerous subcontracting relationships. Modern traceability approaches utilize digital technologies to overcome these limitations. Integrated enterprise systems allow manufacturers and retailers to capture supplier data, production logs, and shipment records within centralized databases. Barcode systems,

RFID tracking, and blockchain platforms are increasingly applied to record product movements and material origins across production stages. These technologies provide continuous visibility of supply chain operations and reduce the risk of undocumented subcontracting. Digital traceability infrastructures also support sustainability verification. Apparel brands increasingly require documentation regarding environmental practices, labor conditions, and responsible material sourcing. Traceability platforms enable companies to verify compliance with certification standards and regulatory requirements. By establishing standardized traceability protocols, organizations can monitor supplier performance more effectively while strengthening transparency across complex textile production networks.

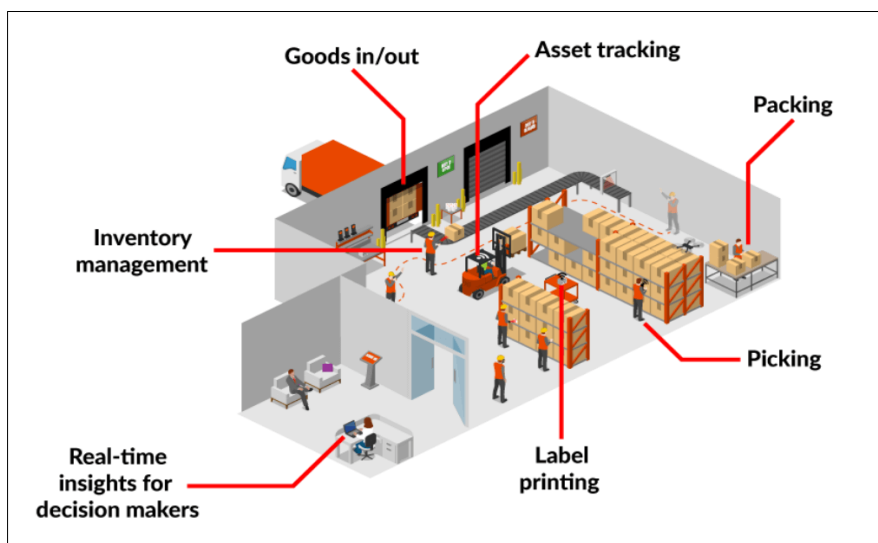


Figure 02: Digital Traceability Technologies in Textile Supply Chains

1.2 Transparency and Compliance in Apparel Manufacturing

Transparency has become a central requirement in global apparel production due to increasing consumer awareness and regulatory expectations. International retailers face growing pressure to demonstrate responsible sourcing practices, including ethical labor standards and environmentally sustainable manufacturing processes. Traceability systems play an important role in supporting transparency by enabling organizations to track production activities across multiple supplier tiers. Compliance monitoring becomes particularly challenging in multi-tier supply chains where second and third tier suppliers may operate independently of primary manufacturing partners.

Without traceability mechanisms, companies often lack visibility into subcontracting arrangements or raw material sourcing practices. Digital traceability systems address this issue by linking production records from different suppliers within a unified documentation framework. Through centralized traceability databases, manufacturers can monitor supplier transactions, verify production capacities, and identify inconsistencies in material flows. Such systems also facilitate audit procedures by providing verifiable documentation of supply chain activities. As a result, traceability frameworks enhance accountability among suppliers while enabling retailers to maintain greater oversight over global apparel production networks.

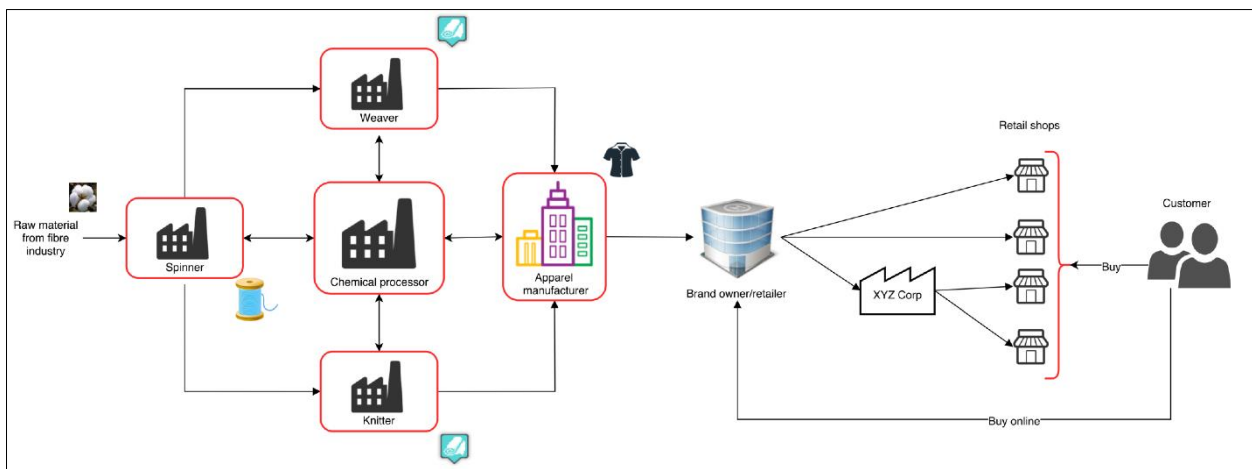


Figure 03: Transparency and Compliance Monitoring in Apparel Supply Chains

II. Related Works

Research on supply chain transparency highlights the importance of traceability systems for improving monitoring capabilities in complex production networks. Early studies examined the role of information systems in enhancing supply chain visibility and coordination among global manufacturing partners [1], [2]. Subsequent research emphasized the need for digital documentation frameworks capable of tracking material flows across multi-tier supply chains [3], [4]. Studies on textile and apparel production networks further demonstrated how supply chain fragmentation complicates monitoring of subcontracting activities and compliance standards [5], [6]. Several scholars have explored the integration of digital technologies into traceability systems for textile production. Blockchain based traceability platforms have been proposed as mechanisms for recording immutable supply chain transactions and verifying production data [7], [8]. RFID tracking and barcode systems have also been widely examined as tools for monitoring inventory movement and product authentication across apparel supply chains [9], [10]. These technologies enable organizations to capture real time information regarding material flows and production stages. Other research emphasizes the importance of traceability for sustainability verification and ethical sourcing initiatives. Studies highlight how

digital traceability frameworks allow companies to document environmental practices and labor compliance within international supply chains [11], [12]. Researchers have also examined the role of supplier information systems in improving coordination among production partners and reducing supply chain risks [13], [14]. Further investigations explore traceability frameworks that integrate supplier databases, transaction logs, and digital documentation systems to strengthen supply chain monitoring [15], [16]. Empirical studies indicate that structured traceability records enhance transparency, facilitate regulatory compliance, and support responsible sourcing initiatives within global apparel production networks [17], [18]. Recent work also suggests that data driven traceability platforms can improve supply chain resilience and strengthen accountability across production tiers [19], [20].

2.1 Digital Documentation and Data Integration

Digital documentation systems are essential for effective traceability in textile supply chains. These systems collect and integrate production data from multiple suppliers and manufacturing stages. By storing transaction records, material certificates, and production logs in centralized databases, organizations can track the movement of goods across different supply chain tiers. Integration of supplier information systems allows

manufacturers and retailers to maintain consistent records and monitor supplier activities throughout the production process.

2.2 Traceability Technologies for Supply Chain Transparency

Technological innovations play a key role in modern traceability frameworks. RFID tags, barcode scanning systems, and blockchain ledgers enable companies to track materials and finished products as they move through production stages. These technologies improve the accuracy of supply chain records while reducing the risk of undocumented production activities. Digital traceability platforms also provide analytical tools that help organizations identify irregularities in supply chain transactions and strengthen transparency across international apparel production networks.

III. METHODOLOGY

The research adopts a qualitative analytical methodology focusing on traceability practices within global textile supply chains. The study examines documentation systems and digital traceability

frameworks used by apparel manufacturers and retailers to track production activities across multiple supplier tiers. Data for the research was collected through analysis of supply chain documentation practices, industry reports, and traceability frameworks used within international textile production networks. The methodological approach focuses on three main analytical components: supply chain mapping, documentation analysis, and traceability system evaluation. Supply chain mapping involves identifying the stages of textile production and the interactions between suppliers operating within each tier. Documentation analysis evaluates how production records, supplier transaction logs, and material certificates are maintained within traceability systems. Traceability system evaluation examines the effectiveness of digital tracking mechanisms in providing transparency across supply chain stages. A conceptual traceability framework was developed based on these analytical components. The framework integrates supplier databases, production documentation systems, and digital tracking technologies to enable consistent monitoring of material flows and production activities across global apparel supply chains.

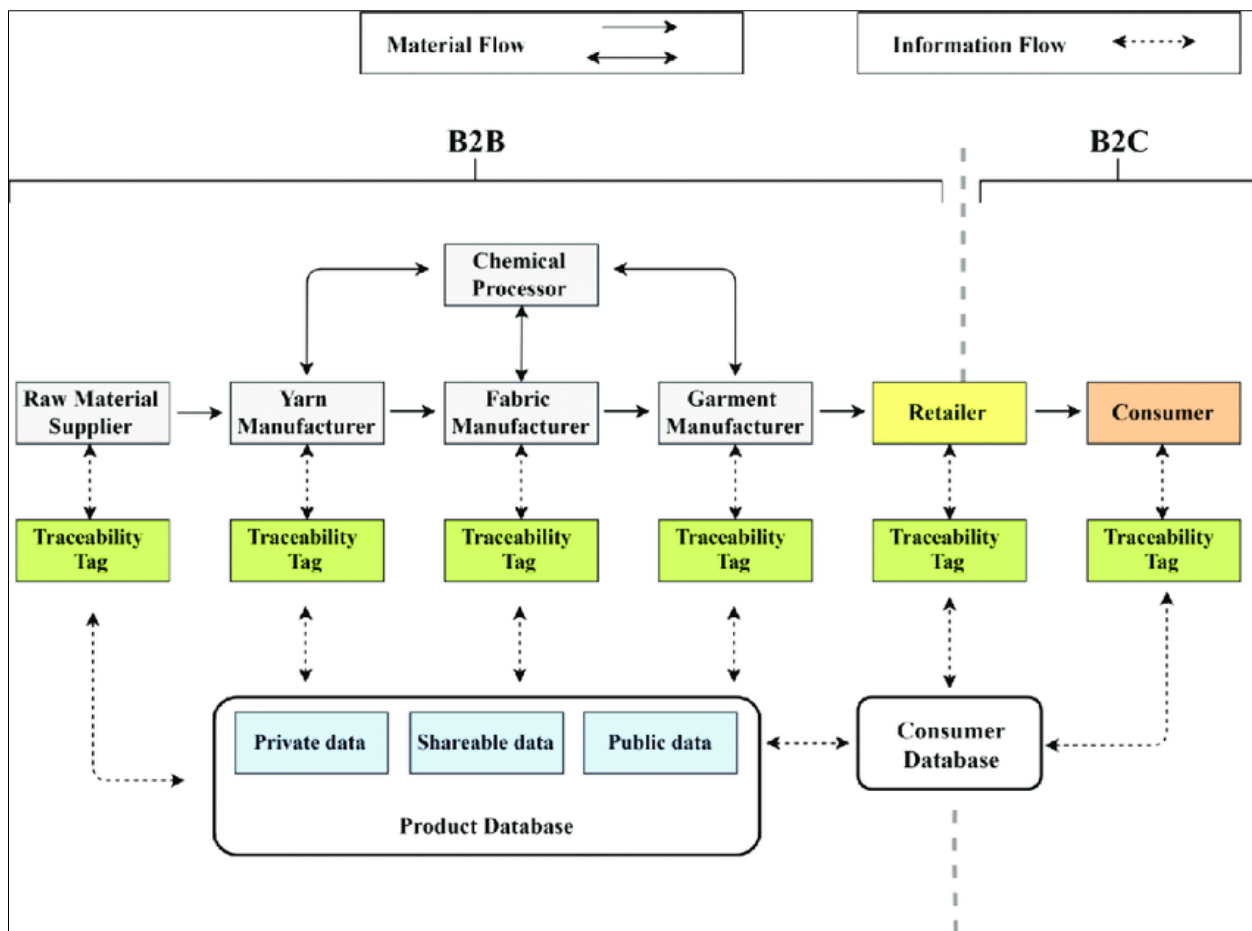


Figure 04: Proposed Textile Supply Chain Traceability Framework

3.1 Framework Validation

The proposed traceability framework was evaluated through scenario analysis of multi-tier apparel

supply chains. The analysis examined how digital documentation systems improve monitoring of supplier transactions and material movements across production

stages. The evaluation focused on the ability of traceability platforms to capture supplier information, record production activities, and maintain consistent supply chain documentation. Results indicate that structured traceability systems significantly improve supply chain visibility. Digital documentation platforms enable manufacturers to verify supplier transactions and monitor production processes across multiple tiers. These systems also reduce information fragmentation by integrating supplier records into centralized databases. As a result, organizations gain improved oversight over complex production networks and can identify inconsistencies in material flows or supplier activities more effectively.

3.2 Compliance Monitoring

Traceability systems also strengthen compliance monitoring in international textile production networks. By maintaining detailed documentation of production activities, organizations can verify adherence to labor standards, environmental regulations, and sourcing requirements. Digital traceability platforms provide verifiable records that support supply chain audits and regulatory reporting. The integration of supplier databases and digital

documentation systems allows companies to detect irregularities in supply chain operations, such as unauthorized subcontracting or undocumented material sourcing. These capabilities enhance accountability among suppliers and contribute to improved governance within apparel production networks.

3.3 Information Integration and Data Transparency

Effective traceability frameworks rely on seamless integration of supply chain information systems. Data transparency is achieved when production records from multiple suppliers are consolidated within unified documentation platforms. These systems provide real time access to supply chain data and enable organizations to analyze material flows and production activities across different tiers. Information integration also facilitates collaboration among supply chain participants. When suppliers share standardized production records through traceability platforms, coordination improves and communication barriers between production stages are reduced. This integration strengthens the reliability of supply chain documentation and supports improved transparency across global apparel production networks.

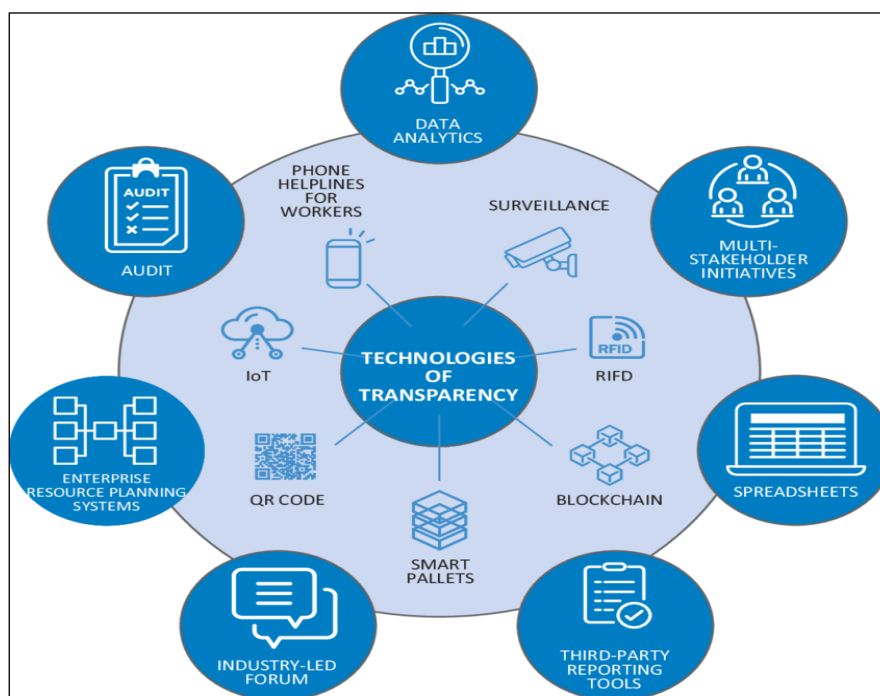


Figure 05: Information Integration and Data Transparency in Multi-Tier Textile Supply Chains

IV. RESULTS AND DISCUSSION

The findings of this research indicate that traceability systems significantly enhance transparency within multi-tier textile supply chains. Digital documentation platforms provide structured records of supplier transactions, material flows, and production activities. These systems enable manufacturers and retailers to track products from raw material sourcing to final garment distribution. Improved traceability also

strengthens supply chain accountability. When suppliers maintain standardized documentation of production activities, organizations can monitor compliance with sourcing policies and regulatory requirements more effectively. Digital traceability systems reduce information gaps between supply chain tiers and support verification of ethical sourcing claims. Furthermore, traceability frameworks contribute to supply chain risk management. By monitoring supplier activities and

production processes, organizations can detect irregularities such as undocumented subcontracting or inconsistencies in material sourcing. These capabilities

allow companies to address potential risks before they affect production operations or brand reputation.

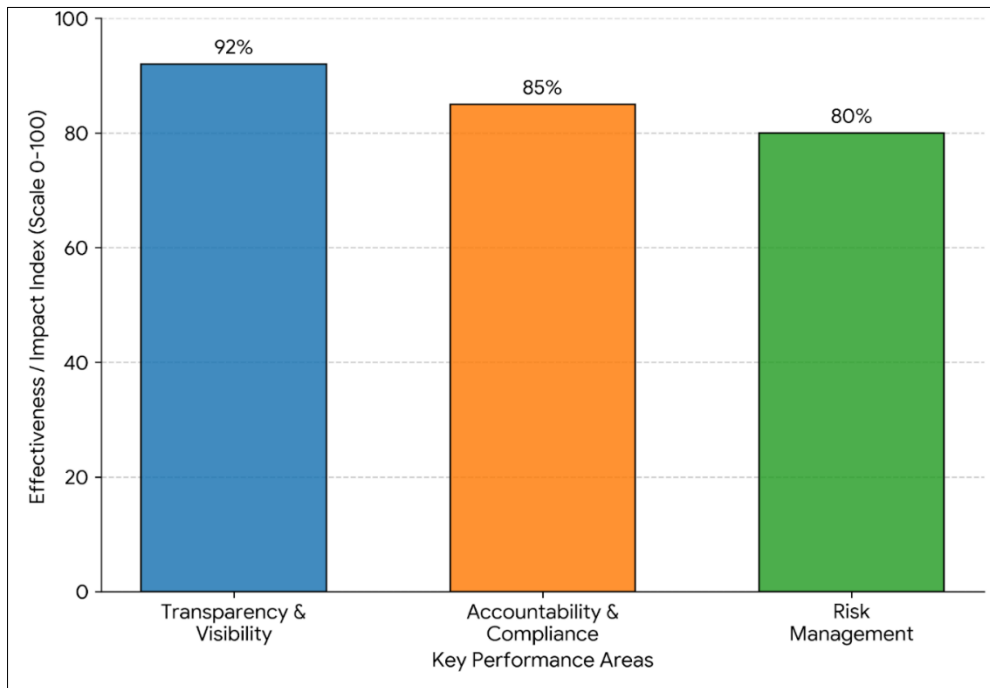


Figure 06: Impact of Digital Traceability Systems on Transparency, Compliance, and Risk Management in Textile Supply Chains

4.1 Supply Chain Visibility Improvements

Implementation of structured traceability systems improves visibility across multiple tiers of textile production. Digital documentation systems allow

companies to track material flows and production activities from fiber sourcing to garment assembly. As a result, organizations gain greater insight into supplier operations and supply chain performance.

Table 1: Supply Chain Visibility Improvements with Digital Traceability Systems

Supply Chain Dimension	Traditional Textile Supply Chains	Traceability Enabled Supply Chains	Observed Improvement
Material Flow Tracking	Limited tracking of raw materials and intermediate products across suppliers	Digital documentation systems record material movement from fiber sourcing to garment assembly	Improved end to end visibility of production stages
Supplier Monitoring	Manufacturers often rely on partial information from first tier suppliers	Integrated traceability platforms provide records of multiple supplier tiers	Greater insight into supplier activities
Production Activity Records	Production data maintained separately by each supplier, often using manual records	Standardized digital production logs stored in centralized documentation platforms	Improved accuracy and consistency of production data
Information Accessibility	Supply chain information scattered across different systems and documents	Real time access to consolidated supply chain data	Faster information retrieval and decision making
Supply Chain Transparency	Limited transparency across subcontracting layers	Unified traceability systems provide detailed documentation of supply chain processes	Increased operational transparency
Operational Monitoring	Monitoring mainly conducted through periodic audits and manual inspections	Continuous monitoring enabled by digital traceability records	Enhanced oversight of production activities
Performance Evaluation	Difficult to assess supplier performance across multiple tiers	Integrated data allows evaluation of supplier efficiency and compliance	Improved supply chain performance assessment

4.2 Transparency and Ethical Sourcing

Traceability frameworks support transparency initiatives in global apparel production. By documenting sourcing practices and production activities, companies can verify compliance with sustainability standards and

labor regulations. This capability is particularly important as consumers increasingly demand transparency regarding the origins and manufacturing processes of textile products.

Table 2: Transparency and Ethical Sourcing Comparison in Textile Supply Chains

Transparency Dimension	Traditional Apparel Supply Chains	Traceability Enabled Supply Chains	Observed Impact
Material Origin Verification	Limited documentation of raw material sources; verification often depends on supplier declarations	Digital traceability records document fiber origin, processing stages, and supplier transactions	Improved ability to verify material origins and responsible sourcing
Labor Compliance Monitoring	Monitoring largely conducted through periodic audits and manual inspections	Continuous digital documentation of production activities and supplier compliance records	Enhanced monitoring of labor practices and regulatory compliance
Supply Chain Visibility	Fragmented information across multiple suppliers and production tiers	Integrated traceability platforms consolidate supplier records and production data	Greater transparency across multi-tier production networks
Sustainability Verification	Environmental and sustainability claims difficult to validate due to incomplete records	Traceability systems document environmental certifications and sustainable production practices	Increased credibility of sustainability reporting
Consumer Transparency	Consumers receive limited information regarding product origin and manufacturing processes	Traceability systems enable brands to disclose sourcing details and production history	Higher consumer trust and informed purchasing decisions
Risk Identification	Difficult to detect unauthorized subcontracting or unethical sourcing practices	Real time monitoring of supplier activities and production records	Faster identification of supply chain irregularities

4.3 Limitations and Future Research

Although traceability systems offer significant benefits, several challenges remain. Implementation of digital traceability infrastructures requires technological investment and coordination among multiple supply chain participants. Smaller suppliers may face difficulties adopting digital documentation systems due to limited resources or technical expertise. Additionally, integration of information systems across geographically dispersed suppliers can present operational challenges. Future research should explore scalable traceability solutions that can be adopted by suppliers of different sizes and technological capabilities. Further studies may also investigate the role of advanced technologies such as artificial intelligence and blockchain in strengthening supply chain transparency and improving traceability across international apparel production networks.

production networks. The proposed framework presents a structured model that connects supplier data, production records, and tracking technologies to support consistent and transparent supply chain operations.

Future research should focus on empirical validation of the proposed framework through case studies and industry-based data analysis. Additional studies may examine the integration of technologies such as artificial intelligence, blockchain, and IoT to improve traceability performance and scalability. Research is also needed to develop cost-effective and adaptable solutions for small and medium-sized suppliers, supporting wider adoption of traceability systems across different production environments.

V. CONCLUSION

This study examined traceability systems in multi-tier textile supply chains and analyzed their role in improving transparency across global apparel production. The findings show that digital traceability frameworks, supported by structured documentation systems and integrated supplier databases, improve visibility, accountability, and compliance monitoring. These systems allow real-time tracking of material flows and production activities, reduce information fragmentation, and strengthen oversight across complex

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