



Enabling Industry 4.0 Skills in Textile SMEs

Supply Chain Management

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1 Objectives

This course aims to provide a comprehensive understanding of supply chain management in the textile industry, highlighting its unique challenges and the transformative role of Industry 4.0 technologies. Participants will explore how innovations such as real-time data collection, data management, and blockchain technology can enhance operational efficiency and transparency. By learning these concepts, participants will be equipped to address contemporary issues in the textile supply chain, ultimately leading to improved performance and competitiveness in the market.

2 Outcomes

2.1 Knowledge

By the end of the course, participants will:

- Understand the core principles of supply chain management and recognize the unique challenges inherent to the textile industry.
- Gain insights into how Industry 4.0 technologies – including real-time data collection, data analysis, and blockchain—can significantly improve transparency, efficiency, and security within the textile supply chain.

2.2 Skills

The module is designed to equip participants with a variety of essential skills that are crucial for success in the dynamic textile field. Through this module, participants will be able to:

- Evaluate the flow of goods from raw materials to finished products.
- Integrate IoT, AI, and blockchain into textile supply chains to enhance efficiency, transparency, and automation.
- Analyse real-time data to enable informed decision-making that optimizes supply chain operations and responds to market demands.
- Analyse and apply blockchain technology to secure and streamline data transactions within the supply chain, ensuring transparency, traceability, and fraud prevention.

3 Introduction

3.1 The supply chain in the textile industry

The term "supply chain" refers to all the activities and processes required for the production and distribution of a particular product or service, from raw materials to the final consumer. It consists of several phases: sourcing (purchasing the necessary raw materials for production), production (transforming raw materials into finished products), distribution (logistics and transportation of the products to retail points), and sales (marketing and commercialization of the products).

The supply chain in the textile sector is characterized by several stages and involves suppliers and manufacturers located in different countries. Today, the fashion supply chain is a complex network of suppliers and sub-suppliers spread across the globe, making it challenging to have an overall view and monitor the individual stages of production and the actors involved.

While there is no single model for a fashion supply chain due to the wide variety of products and processes involved, we can simplify it into a similar structure with different tiers:

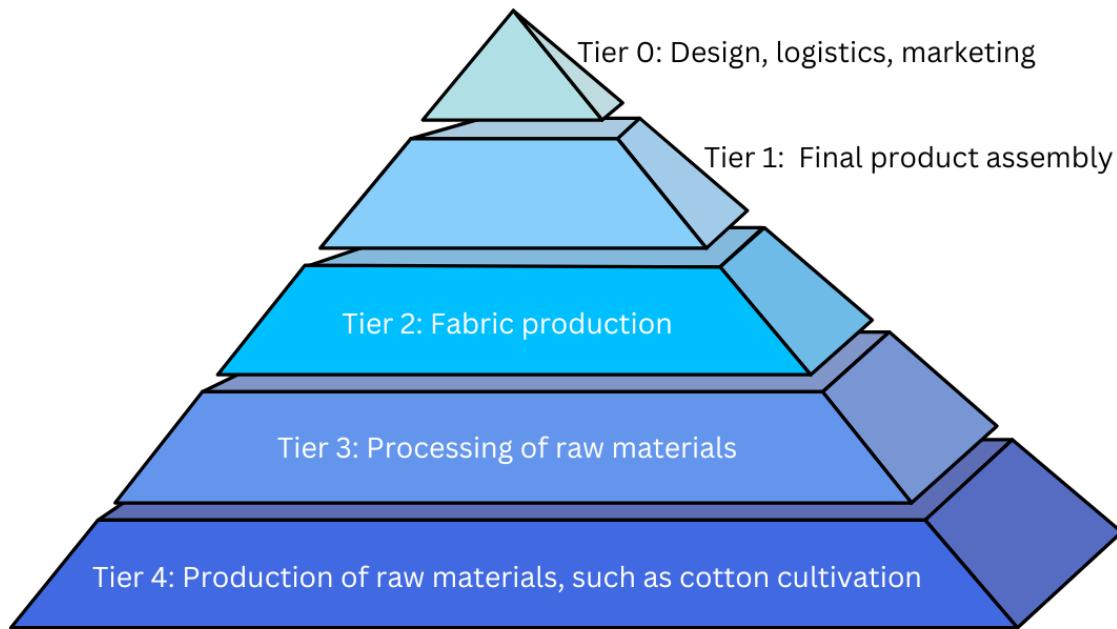


Figure illustrating the tiers of the supply chain.

Created by author.

On average, in Tier 1 alone, each established brand operates with a network of between 300 and 3,000 suppliers, each of which may have between 50 and 200 additional suppliers.

The landscape that brands face is therefore extremely intricate, composed of various actors and sustainability challenges. For instance, a company focused on cotton cultivation encounters entirely different environmental issues compared to one involved in cutting and tailoring. Moreover, due to the vast distances separating these companies, they are often subject to different regulations. This makes it difficult for a single brand to monitor compliance across all its suppliers effectively.

3.2 Supply Chain Management

Supply chain management (SCM) in the textile sector is a fundamental process that coordinates all the activities required to take a product from design to sale, addressing the specific challenges of a constantly evolving market that is increasingly focused on sustainability.

Supply chain management (SCM) is therefore crucial for the success of the textile and apparel industry. It involves managing the flow of resources—from raw materials to finished products—ensuring that they are available in the right place, at the right time, and in the right quantities, all while minimizing costs. Key Benefits of effective SCM are:

- Improved Logistics:** Effective SCM enhances logistics by optimizing the movement of goods and fostering collaboration among suppliers. This ensures timely delivery and reduces bottlenecks in the supply chain.
- Flexibility:** A robust supply chain allows companies to be flexible, enabling them to respond quickly to changes in consumer demand or fluctuations in the market. This adaptability is vital in a competitive environment.
- Cost Reduction:** By streamlining processes and minimizing waste, effective SCM contributes significantly to reducing total production and logistics costs. This is particularly important in an industry facing rising production expenses.

4. Optimal Resource Utilization: SCM ensures that materials are used efficiently and effectively, maximizing the value derived from available resources. This not only improves profitability but also supports sustainable practices.

4 Challenges in Textile Supply Chains

The textile industry navigates a complex landscape filled with unique challenges that stem from various factors, including fluctuating consumer demand, inventory management issues, logistic delays, quality control and environmental compliance. One of the most pressing challenges is **variability in consumer demand**. The textile industry is closely tied to the fashion sector, which is characterized by rapid changes in trends and preferences. This volatility can lead to significant fluctuations in demand, making it difficult for companies to predict what products will be popular at a given time. Fast fashion brands use to launch multiple seasons each year, sometimes up to 40, to keep pace with changing consumer tastes. This fast fashion model places immense pressure on manufacturers to produce and deliver goods quickly while managing costs effectively.

Logistics delays further complicate the supply chain landscape in the textile sector.

Transportation issues can disrupt delivery schedules, leading to customer dissatisfaction and potential loss of business. Factors such as geopolitical tensions, natural disasters, and global pandemics have highlighted the vulnerabilities within supply chains. The rapid circulation of information has become more accessible than ever before, facilitating the rise of conflicts both on a global level and between collaborators, particularly regarding political concerns. An important example of this volatility is the United Kingdom's exit from the European Union (Brexit). Prior to this

event, industries within the UK were deeply intertwined with the markets in Europe, with cross-border supply chains playing an essential role. The European Union, as the UK's most significant trading partner, thus held a crucial position not only within the regional economic framework but also in the broader global economy.

To address these geopolitical volatilities and logistical challenges, companies must enhance their logistics strategies by diversifying transportation routes, investing in local suppliers, and leveraging technology for better tracking and coordination of shipments.

The growing emphasis on **environmental compliance** poses a significant challenge for the textile industry. With increasing awareness of sustainability issues among consumers, brands are under pressure to demonstrate their commitment to environmentally friendly practices. This includes providing transparency about sourcing materials and manufacturing processes while adhering to regulations related to waste management and resource conservation. Companies must invest in sustainable technologies and practices that not only minimize their environmental impact but also resonate with eco-conscious consumers.

Quality control is another paramount concern for textile manufacturers. Ensuring consistent product quality throughout the supply chain is crucial; any failure in quality can result in costly returns and damage a brand's reputation. As consumers become more discerning about product quality and ethical sourcing practices, companies must implement comprehensive quality assurance protocols at every stage of production.

This includes rigorous testing of raw materials and finished products to meet both consumer expectations and regulatory standards.

While Industry 4.0 is not a guarantee for flexibility in the supply chain, it can provide certain tools such as higher quality of data, increasing knowledge, analytical understanding and data security which can help to optimize the operations of the business.

5 Industry 4.0 Technologies in Supply Chain Management

Industry 4.0, otherwise known as the Fourth Industrial Revolution, refers to the ongoing transformation of industries through the integration of advanced digital technologies. For the textile and apparel companies it is crucial to apply 4.0 technology in managing the supply chain in order to be competitive and meet the rapid demand of today's customers regarding lead times, quality and the environmental impact of textiles and garments. The most important consequences of the Fourth Industrial Revolution relate to consumer expectations, collaborative innovation and organizational forms as well as product and process improvement. An important aspect to underline is that customers are the center of the economy, and this makes every aspect that leads to improved ways of customer experience an essential focus. For businesses and producers, it will be essential to implement Industry 4.0 technologies in supply chains to become more efficient, comply with increasing regulatory requirements, and remain competitive.

Let's look at several innovative solutions aimed at addressing challenges and enhancing textile supply chain management through digitalization and the application of Industry 4.0 technologies:

Internet of Things (IoT): One of the key challenges in the textile industry is logistics delays and supply chain disruptions. To counter this, IoT-connected sensors enable real-time monitoring of raw materials and finished products,

tracking parameters such as temperature, humidity, geolocation, and stock levels. Sensors and RFID tags exhibit real-time data of products, equipment, robots, devices, and machinery.

- **Solution to Logistics Delays:** Sensors embedded in shipments provide live updates, allowing companies to react proactively to any delays and optimize transportation routes.
- **Solution to Quality Control Issues:** Smart sensors track key parameters such as dyeing consistency and fabric tension throughout production, ensuring uniform quality and minimizing defects.
- **Solution to Consumer Demand Variability:** Real-time inventory tracking allows brands to restock popular items efficiently, preventing overproduction and dead stock.

Big Data, Analytics and Artificial Intelligence (AI): The textile industry faces the challenge of variability in consumer demand. AI-driven big data analytics optimize inventory management and forecast trends more accurately while automating decision-making processes and minimizing human error.

- **Solution to Demand Fluctuations:** AI algorithms analyze real-time sales data, historical trends, and social media insights to predict upcoming fashion trends, allowing manufacturers to adjust production dynamically.
- **Solution to Quality Control Issues:** Machine vision systems powered by AI analyze fabric quality and detect defects in real-time, reducing manual inspection errors and improving overall product consistency.
- **Solution to Environmental Compliance:** Big data analytics optimize resource utilization, reducing waste and improving energy efficiency in textile production.

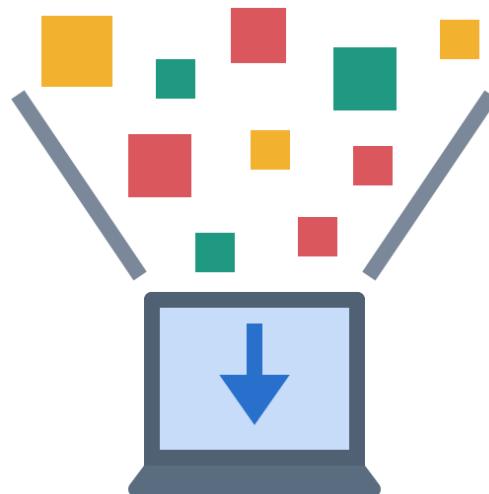
Blockchain: Environmental compliance and ethical sourcing are growing concerns in the textile industry. Blockchain technology provides a decentralized ledger that securely records transactions, ensuring transparency throughout the supply chain.

- **Solution to Sustainability Challenges:** Blockchain enables brands to track the origins of raw materials, ensuring ethical sourcing and compliance with sustainability standards.
- **Solution to Logistics and Fraud Prevention:** Secure transaction records enhance trust among suppliers and logistics partners, reducing counterfeit risks and improving supply chain coordination.
- **Solution to Quality Assurance:** Smart contracts automatically enforce compliance with quality and delivery standards, minimizing human errors and streamlining processes.

Additive manufacturing and 3D printing: This is the opposite of subtractive manufacturing: a process of creating objects working layer by layer. 3D printing is a type of additive manufacturing. This technology is particularly interesting for its potential applications in the fashion industry, because the need for rapid adaptation to fashion trends requires textile manufacturers to develop products quickly while minimizing waste.

- **Solution to Rapid Demand Changes:** 3D printing allows for on-demand manufacturing of samples and small-batch production, reducing lead times and preventing overproduction.
- **Solution to Environmental Impact:** By utilizing additive rather than subtractive manufacturing, companies can significantly reduce material waste and energy consumption.

Industry 4.0 technologies facilitate the collection of vast amounts of real-time data, secure transmission, and provide comprehensive analysis. When working synergically, they can have a great impact enhancing informed decision-making and implementing more effective processes to enhance supply chain performance. Let's take a closer look.



Icon from [Flaticon](#)

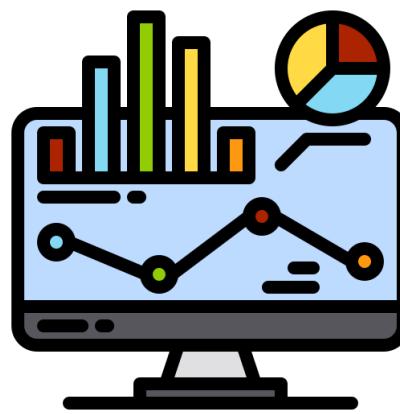
5.1 Real-time data collection and connectivity

Real-time data collection is pivotal for enhancing textile supply chain management. The use of IoT and IIoT sensors is a cornerstone of this strategy, as these devices can monitor various parameters such as temperature, humidity, geolocation, and stock levels throughout the supply chain. Sensors embedded in shipments provide live updates, allowing companies to react proactively to any delays and optimize transportation routes. By deploying sensors in warehouses and transportation vehicles, companies gain immediate insights into the status of raw materials and finished products. When they are incorporated into packaging, they provide information about shipments, customer orders, and stock levels. This capability not only optimizes inventory management and reduces lead times but also helps in facilitating proactive decision-making and identifying potential issues before they escalate into significant problems.

To effectively gather real-time data, organizations can leverage a variety of tools and techniques. Streaming platforms like Apache Kafka and Amazon Kinesis enable the seamless transmission of data from multiple sources, ensuring that information is available for analysis as it is generated. These platforms are designed to handle high volumes of data with low latency, making them ideal for applications requiring

immediate visibility into supply chain operations. Additionally, advanced analytics tools can process this data in real time, allowing businesses to detect anomalies and respond swiftly to changing conditions.

Mobile applications equipped with data collection functionalities can enhance the efficiency of real-time monitoring. For instance, field workers can input data directly from their mobile devices, capturing critical information on the go. This integration of mobile technology not only streamlines data collection but also enriches the dataset with real-time insights from various operational touchpoints.



Icons from [Flaticon](#)

5.2 Advanced data analytics and AI for decision-making

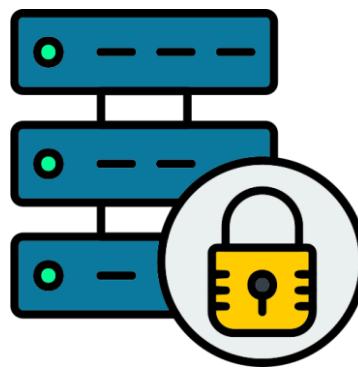
The influx of data generated by IoT devices and other sources necessitates robust data management strategies to harness its full potential. Effective data utilization begins with establishing a clear framework for data governance, which includes defining roles and responsibilities for data handling across the organization. This framework ensures that data quality is maintained and that stakeholders can trust the information being analyzed.

AI-driven big data analytics optimize inventory management and forecast trends more accurately while automating decision-making processes and minimizing human error. AI algorithms analyze real-time sales data, historical trends, and social media insights to predict upcoming fashion trends, allowing manufacturers to adjust production

dynamically. Additionally, machine vision systems powered by AI analyze fabric quality and detect defects in real-time, reducing manual inspection errors and improving overall product consistency.

Big data analytics also optimize resource utilization, reducing waste and improving energy efficiency in textile production. Big data has a limited direct effect on the supply chain execution. The effect is depending on resilience and flexibility of the supply chain. **Resilience** in the supply chain means to have a low effect of interference and a high paced recovery from interferences. The **flexibility** instead is about enlarging use of resources to synchronize with market demands which leads to improvement of operations and increased customer satisfaction. Organizations need to adopt technological infrastructure to optimize the analytics from big data on a data-driven approach to informed decision-making. Tools like Apache Flink and Google Cloud Dataflow enable businesses to conduct intricate analyses on streaming data while maintaining scalability and performance. These platforms support both batch and real-time processing, allowing organizations to extract actionable insights that can enhance inventory management and demand forecasting.

Predictive analytics techniques play a crucial role in decision-making processes within the textile supply chain. By examining historical data in conjunction with real-time inputs, companies can better identify trends and accurately forecast future demands. AI can be a powerful tool in optimizing production schedules, minimizing waste, and ensuring that resources are allocated efficiently to meet market demands.



Icônes from [Flaticon](https://www.flaticon.com)

5.3 Blockchain for transparency and security

Blockchain technology has transformative potential for improving traceability and security in the textile supply chain. By providing a decentralized ledger that transparently records all transactions, blockchain ensures that every participant in the supply chain has access to accurate and immutable information regarding product provenance and transaction history. This transparency fosters trust among partners, as each entity can verify the authenticity of goods at any point in their journey.

The application of blockchain extends beyond simple transaction records; it also plays a vital role in protecting intellectual property rights within the textile industry. **Smart contracts**—self-executing contracts with terms directly written into code—automate compliance checks and ensure that all parties adhere to agreed-upon standards regarding quality and delivery timelines. This automation reduces human error and enhances operational efficiency by streamlining processes that would otherwise require manual oversight.

Additionally, blockchain's capacity to maintain secure records significantly mitigates risks associated with fraud and counterfeiting. In an industry where brand integrity is paramount, having a reliable method for tracking goods from production to retail helps protect against unauthorized reproductions or misrepresentations of products. Consequently, consumers can have greater confidence in their purchases, knowing they are receiving genuine products backed by verifiable histories. Blockchain technology also enhances logistics and fraud prevention, as secure transaction records improve trust among suppliers and logistics partners, reducing counterfeit risks and improving supply chain coordination.

5.4 Smart manufacturing and sustainable production

The need for rapid adaptation to fashion trends requires textile manufacturers to develop products quickly while minimizing waste. Additive manufacturing, including 3D printing, provides an innovative solution to this challenge. Unlike traditional subtractive manufacturing, 3D printing builds objects layer by layer, which not only allows for on-demand production but also reduces material waste.

By utilizing additive rather than subtractive manufacturing, companies can significantly reduce material waste and energy consumption, making it a key contributor to environmental sustainability. This capability enables the production of samples and small-batch runs without the need for expensive and time-consuming retooling processes. Consequently, manufacturers can respond swiftly to shifting consumer demands while maintaining cost efficiency.

AI also plays a significant role in optimizing smart manufacturing processes. AI-driven automation can streamline production workflows, enhancing operational efficiency and reducing resource consumption. AI-enabled systems analyze production data in real-time to identify inefficiencies, detect quality issues, and optimize material usage, ensuring that sustainability remains a priority in textile production.

6 Transparency and Traceability for Sustainable Supply Chains

Globalization has significantly fragmented supply chains, moving much of the manufacturing that was once local to developing nations in search of lower labor costs and proximity to raw materials. This shift has complicated the tracking of production cycles, contributing to a system that often lacks transparency and obscures poor working conditions.

For fashion and textile brands, it is crucial to implement structured strategies aimed at enhancing **traceability and transparency** within their operations. By gathering reliable information about their production processes and sharing it with all stakeholders, brands can better identify negative environmental and social impacts associated with their activities. Transparency also creates a more reliable image of the brand or product and can increase customer loyalty and therefore have recurring customers. As a part of traceability and transparency the digital product passport plays a vital role. To have the most optimal DPP it is important to combine the different technologies. Internet of things, to collect data, AI to curate data and last Blockchain for leverage and sharing. This is the most frequent combination. They add value independently but most optimal when united in a combination. Challenges in terms of technology, regarding digital product passports are for instance, the format, content in relation to

data requirements, confirming post-launch data progression and lastly, approval of accessibility regarding digital infrastructure of the production entities.

The textile value chain's production phase is particularly intricate and opaque, involving numerous participants—many of whom are small and medium-sized enterprises (SMEs) or informal entities—at every stage from raw material extraction to the final product. While some manufacturers may operate integrated systems that consolidate many activities within a single business unit, often 15 to 20 different companies are involved in various processes between sourcing raw materials and assembling products. Traders frequently facilitate the exchange of these materials and products among businesses. These complex commercial relationships are usually not tracked due to their informal nature, leading to a lack of transparency that can change rapidly unless intentionally structured into fixed or shorter supply chains. Consequently, many producers may unknowingly be part of a major brand's supply chain, complicating efforts to detect, prevent, and mitigate the impacts associated with production phases.

To effectively verify compliance with traceability principles across a globally dispersed supply chain, brands can implement several strategies and utilize various technologies.

- **Utilizing Traceability Platforms:** Brands can leverage platforms like the **Business Social Compliance Initiative (BSCI)**, **Higg Index**, and **Trustrace** to collect and analyze data on suppliers. These platforms assess parameters such as employee conditions, safety measures, and compliance with labor standards. By choosing suppliers that demonstrate responsible practices, brands can enhance their supply chain integrity.
- **Adopting Blockchain Technology:** Blockchain serves as a secure digital ledger that records every transaction in the supply chain. This technology provides a transparent and tamper-proof record of product origins and movements, enabling brands to trace materials back to their source. Companies like **Crystalchain** and **Textile Genesis™** offer blockchain solutions tailored for supply chain traceability.
- **Implementing RFID and Barcoding Systems:** Brands can employ RFID tags and barcodes to track products throughout the supply chain. These technologies

facilitate real-time monitoring of materials, ensuring that brands can verify their origins and the conditions under which they were produced.

- **Establishing Strong Supplier Relationships:** Building long-term partnerships with vertically integrated suppliers can enhance traceability. By reducing the number of intermediaries, brands gain better control over their supply chains, making it easier to monitor compliance with labor and environmental standards.
- **Data Integration and Standards Compliance:** A robust data integration strategy is essential for effective traceability. Brands should establish clear standards for data sharing among partners, ensuring that information about raw material sources, sustainability metrics, and supplier practices is consistently recorded and accessible.

7 Conclusions

As we have seen, the integration of industry 4.0 technologies are crucial for improving both the efficiency and sustainability in textile supply chains. Digitalization through IoT, big data, AI, and blockchain offers practical solutions to the sector's unique challenges, such as logistics complexity, inventory management, and demand variability. These technologies empower organizations to collect and analyze real-time data, optimizing decision-making processes and improving supply chain visibility.

Specifically, IoT and real-time data help companies to track the movement of resources and product, reducing delays and inefficiencies in the supply chain. AI automates decision-making, enhancing responsiveness to demand fluctuations while minimizing human error. Meanwhile blockchain, enhances transparency and ensures secure transactions, fostering trust between partners and enabling precise traceability, which is critical for sustainability goals.

The integration of these technologies not only boosts operational efficiency but also drives sustainability. With enhanced traceability, businesses can more effectively monitor and certify the environmental and social impact of their suppliers, addressing growing consumer and regulatory pressures for greater transparency in supply chain

practices. Adopting advanced technologies can improve efficiency, competitiveness, and promote responsible supply chain management. Ultimately, Industry 4.0 technologies are key to addressing the sector's current challenges and building a more sustainable future for the textile industry.

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