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Postgraduate Dissertation
“Leveraging Digital Technologies and Innovation Practices for
Strategic Supply Chain Management to achieve resilience and
sustainability”

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Patras, Greece, “May” “2025”

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**“Leveraging Digital Technologies and Innovation Practices for
Strategic Supply Chain Management to achieve resilience and
sustainability”**

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Abstract

The thesis explores the integration impact, state-of-the art technologies and innovation practices have on enhancing the strategic supply chain management, as well as defining the key factors that orient companies towards the supply chain digitalization path supporting greater sustainability and resilience. It sets the background by outlining the supply chain status and defining the challenges it faces in today’s volatile, uncertain, complex and ambiguous (VUCA) environment. Factors such as lack of adequate visibility, disruptions and environmental concerns underline the urgency for strategic evolution. The research investigates emerging digital technologies and their strategic impact (forecasting, collaboration, transparency, decision-making) across the supply chain, as well as innovation practices, such as the circular supply chain model, to mitigate risks, optimize processes and address market fluctuations aiming in cost-effectiveness and reduced environmental footprint. Through a structured approach, implementing the DEMATEL method, key factors for resilience and sustainability integration are identified. Furthermore, a case study from the plastic manufacturing sector illustrates a company’s evolvement from traditional operation toward a digital supply chain, outlining the importance of technologies. The analysis of the company’s status reveals that end-to-end visibility, data-driven insights, automation and continuous improvement can significantly enhance strategic supply chain management outcomes. A comparison is made between the strategic importance of the key factors and the technology strategic impact as defined in the thesis with the case study showcasing that although concrete steps are being made, there is still remaining actions to be taken.

This thesis demonstrates that leveraging digital technologies and innovation practices enables companies to not only enhance operational efficiency but also build a robust, future-ready supply chain that remains resilient and sustainable in a rapidly changing global context.

Keywords

Supply Chain 4.0, resilience, circularity, digital technologies

Περίληψη

Η διπλωματική εργασία εξετάζει τον αντίκτυπο των καινοτόμων τεχνολογιών και πρακτικών στην ενίσχυση της στρατηγικής διαχείρισης της εφοδιαστικής αλυσίδας, καθώς και τους βασικούς παράγοντες που προσανατολίζουν τις εταιρείες προς την ψηφιοποίησή της, υποστηρίζοντας μεγαλύτερη βιωσιμότητα και ανθεκτικότητα. Παρέχει το θεωρητικό υπόβαθρο περιγράφοντας την τρέχουσα κατάσταση της εφοδιαστικής αλυσίδας και προσδιορίζοντας τις προκλήσεις που αντιμετωπίζει στο σύγχρονο ασταθές, αβέβαιο, περίπλοκο και αμφίβολο (VUCA) περιβάλλον. Παράγοντες όπως η έλλειψη ορατότητας (visibility), διαταραχές (disruptions) και περιβαλλοντικές ανησυχίες υπογραμμίζουν την αναγκαιότητα στρατηγικής εξέλιξης. Η έρευνα μελετά τις αναδυόμενες ψηφιακές τεχνολογίες και το στρατηγικό τους αντίκτυπο (π.χ. πρόβλεψη, συνεργασία, διαφάνεια, λήψη αποφάσεων) σε όλο το εύρος της εφοδιαστικής αλυσίδας, καθώς και καινοτόμες πρακτικές, όπως το κυκλικό μοντέλο εφοδιαστικής αλυσίδας, για τη μείωση κινδύνων, τη βελτιστοποίηση διαδικασιών και την αντιμετώπιση διακυμάνσεων της αγοράς με στόχο την αποδοτικότητα κόστους και τον περιορισμό του περιβαλλοντικού αποτυπώματος. Μέσω μιας δομημένης προσέγγισης με εφαρμογή της μεθόδου DEMATEL, εντοπίζονται οι βασικοί παράγοντες που συμβάλλουν στην ενσωμάτωση της ανθεκτικότητας και της βιωσιμότητας. Επιπλέον, παρουσιάζεται μελέτη περίπτωσης από τον κλάδο παραγωγής πλαστικών, η οποία απεικονίζει τη μετάβαση μιας επιχείρησης από μια παραδοσιακή σε μια ψηφιακή εφοδιαστική αλυσίδα, τονίζοντας τη σημασία των τεχνολογιών. Η ανάλυση της κατάστασης της εταιρείας δείχνει ότι η ορατότητα, η αξιοποίηση δεδομένων για τη λήψη αποφάσεων, ο αυτοματισμός και η συνεχής βελτίωση μπορούν να ενισχύσουν σημαντικά τα αποτελέσματα της στρατηγικής διαχείρισης της εφοδιαστικής αλυσίδας. Παράλληλα, γίνεται σύγκριση ανάμεσα στη στρατηγική σημασία των βασικών παραγόντων και στο στρατηγικό αντίκτυπο της τεχνολογίας, όπως αυτά ορίζονται στη διπλωματική εργασία, με τη μελέτη περίπτωσης να καταδεικνύει ότι, παρόλο που έχουν γίνει συγκεκριμένα βήματα, απομένουν ακόμη ενέργειες για την περαιτέρω εξέλιξη.

Η εργασία καταδεικνύει ότι η αξιοποίηση των ψηφιακών τεχνολογιών και των καινοτόμων πρακτικών επιτρέπει στις επιχειρήσεις όχι μόνο να ενισχύσουν τη λειτουργική τους αποδοτικότητα, αλλά και να αναπτύξουν μια ανθεκτική εφοδιαστική αλυσίδα, ικανή να παραμείνει βιώσιμη σε ένα ταχύτατα μεταβαλλόμενο παγκόσμιο περιβάλλον.

Λέξεις – Κλειδιά

Εφοδιαστική αλυσίδα 4.0, ανθεκτικότητα, βιωσιμότητα, ψηφιακές τεχνολογίες

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List of Abbreviations & Acronyms

AI	Artificial Intelligence
AR	Augmented Reality
CAGR	Compound Annual Growth Rate
CE	Circular Economy
DEMATEL	Decision Making Trial and Evaluation Laboratory
EBIT	Earnings Before Interest and Taxes
EC	European Commission
EU	European Union
IoT	Internet of Things
KPI	Key Performance Indicator
OEM	Original Equipment Manufacturer
RFID	Radio Frequency Identification
VUCA	Volatile, Uncertain, Complex, Ambiguous
WEF	World Economic Forum

1. Introduction

In today's dynamic business environment, digitalization has become a transformative force shaping the evolution of supply chains. The role of digital technologies within supply chain management is critical, as they fundamentally alter the processes through which goods and services are produced, distributed, and ultimately delivered to consumers. The integration of digital solutions into supply chain operations is no longer a mere choice but a strategic necessity for businesses aiming to not only preserve their competitive advantage but also to ensure their long-term survival in an increasingly complex and fast-paced market. As industries face heightened pressures for efficiency, flexibility, and responsiveness, embracing digitalization has become indispensable for organizations seeking sustainable growth and resilience.

1.1 Overview of Supply Chain

The term Supply Chain Management was first introduced in 1982 by Keith Oliver and Melvin Webber aspiring to describe the business of moving goods around the world (Webber, Melvin, 1982), although the concept had started shaping years ago. According to Investopedia, lastly updated in June 13, 2024, Supply Chain is *“a network of individuals and companies that are involved in creating a product and delivering it to the consumer”* (Hayes, 2024). In more details, the supply chain (management) refers to the management and coordination of activities, processes and resources, incorporating each stage of a process from sourcing raw materials to the different steps of processing them, distributing the finished products to sale centers and finally delivered to customers. Across this long chain, different stakeholders are included such as producers, warehouses, transportation companies and logistic managers. The high number of stakeholders included through interconnected tasks and various activities increase the supply chain complexity and multiply the difficulty for businesses to address and ensure demand and supply requirements while its well-management is crucial to ensure efficiency, cost minimization and customer satisfaction enhancement.



Figure 1: A typical supply chain(Supply Chain).

It is important to note that a supply chain is not only focused on a single product flow, but could potentially include different product flows (according to the business’ final product catalogues), thus having to coordinate efficiently not only different stakeholders, but also multiple stakeholders in the same supply chain stage (e.g. raw material providers). This dynamic and integral aspect of operations reduces the degree of freedoms and thus the margin for errors and delays.

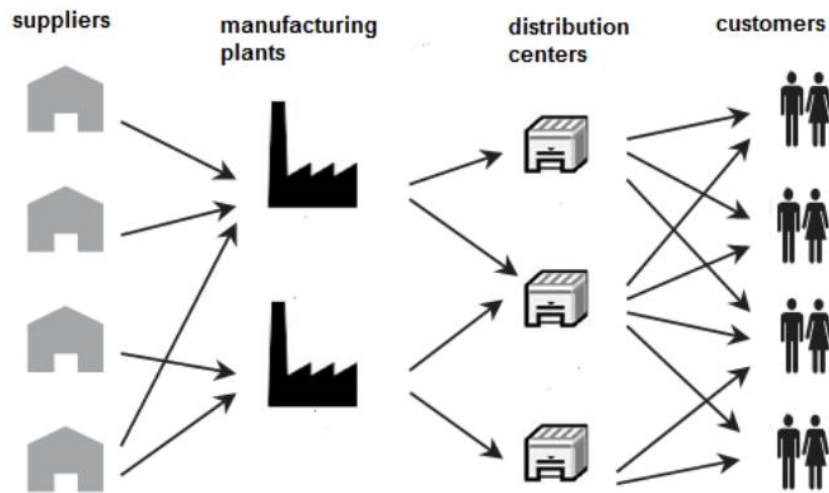


Figure 2: Schematic representation of supply chain network(Gholami, 2014).

Figure 1 presents a representation of a supply chain network that involves multiple stakeholders at the different supply chain stages (suppliers, manufacturing plants, distribution centers, customers). A real-world supply chain includes a higher number of partners, intermediate activities and connections increasing the need for efficient control.

According to the Fortune Business Insights report (<https://www.fortunebusinessinsights.com/supply-chain-management-market-102977>), the Supply Chain Management market was valued at €22,67 billion in 2023 and is projected to grow from €25,24 billion in 2024 to €61.31 billion by 2032, exhibiting a CAGR of 11.7% during the forecast period. This increase can be attributed to different factors such as the advance of technology, the business’ needs to address unexpected disruptions and their aim to increase competitiveness, leading the supply chain leaders towards new business models. Although, actions are being taken towards evolution, still the supply chain upgrade lacks behind.

A McKinsey survey in 2023 (Alicke, 2023) reported that 44% of their respondents stated major challenges arising from their supply chain footprint and 49% mentioned that supply chain disruptions had caused major planning challenges affecting their overall competitiveness. However, steps have been taken to a digitalization pathway of the supply chain. A survey from ProcurementTactics (Overvest, 2024), reports that 63% of organizations have implemented technological solutions to monitor and assess the efficiency of their supply chains to enhance resilience and reduce risk, while 55% of G2000 OEMs will redesign service supply chains using AI by 2026. This means that over half of these major manufacturers will use artificial intelligence to overhaul how they handle their service operations. Nonetheless, a report from PwC (*PwC’s 2024 Digital Trends in Operations Survey*, 2024) stated that 69% of operations and supply chain officers say tech investments haven’t fully delivered expected results.

1.2 Problem statement

Turbulent market environments and uncertain networks the last years have undoubtedly disrupted in various ways the manufacturing industry in terms of operation and value chains of the production, unravelling the growing need for differentiation from yesterday's rationale. The continuously increasing demand for products and services defines the current business environment as highly competitive. Unexpected events, disruptions or obstacles consist crises that companies must address to set their position not only towards leading the market but also to ensure survival. In parallel, new regulations, globalization, client discretion and environmental factors contribute to the pressure companies are accepting creating strategic challenges.

As it is clearly stated in the Manufuture 2030 vision document (ManufutureHLG, 2018), manufacturing industry has to face challenges of driving competitiveness, resilience, sustainability and circularity in the context of a Volatile, Uncertain, Complex and Ambiguous (VUCA) environment. In fact, a VUCA world calls for new capabilities on the manufacturing systems demanding evolution from industrial automation towards industrial autonomy. This transition from traditional manufacturing regimes births new challenges and sets the focus on new collaborative product-process-service engineering and manufacturing paradigms that reconcile the need for increased customer-centric responsible value creation networks, modernization of production systems with technology intelligence powered by AI and simulations.

According to a survey from WEF in 2022 (WEF, 2022) carried out with more than 400 senior executives in operations and supply chains, only 12% of manufacturing companies were sufficiently protected against future disruptions from external events while 36% demonstrated the need to take immediate action to build resilience and flexibility in their manufacturing processes. According to an ACCENTURE report (Resilience in the Making, 2023), disruptions caused €1.54 trillion in missed revenue, with the Industrial Equipment manufacturing to be the most impacted industry (€416.30 billion). In fact, as EC indicates, failing to develop innovative manufacturing resiliency features, companies can expect only supply chain disruptions to erase half a year's worth of profits or more. Thus, there is a challenge and an opportunity to set the foundations and leverage the data-driven technologies for integrating active resilience strategies respecting EU digital values (excellence, privacy, trust) to improve individual and value chain flexibility. Already, the WEF identified 7 active resilience strategies addressing both demand and supply resilience (WEF, 2024), that can be facilitated with the integration of new technologies.

The supply chain digitalization can lead to significant cost savings and profitability for companies, with benefits such as efficiency and automation, improved decision-making, collaboration and connectivity, data-driven planning and analysis, and improved customer experience. Companies can achieve 20% lower operating costs and 11% EBIT (Watukara, 2023) and there is already actions towards leveraging digital technologies, more specifically a study by Capgemini showed that 68% of supply chain organizations are leveraging AI-enabled solutions (Amit, 2024).

1.3 Significance of the study and objectives

Resilience and sustainability are two concepts that have received considerable attention from the European community the recent years and have shaped its strategic goals for the next decade. As already mentioned in the previous chapters, businesses are faced with a multitude of cross-dimensional challenges (e.g. COVID19, Ukraine war) leading to significant issues in productivity and supply. While supply chains demonstrate efficiency in stable environments, they are susceptible to risks and disruptions. Businesses have been called upon to confront first time issues and efficiently answer to modern changes exploiting their traditional supply chains. One of the most important disruptions the latest years was the pandemic outbreak in 2019 which greatly impacted the supply chains (Harapko, 2023). This situation have revealed the supply chain vulnerability and fragility, for example as the production of a product many times depends on suppliers located in different parts of the world. The huge uncertainties in supply and demand highlight the importance to adequately handle risks and increase supply chain robustness. Thus, there is a growing need to address the optimization of supply chain management, incorporating new strategies, innovation practices and state-of-the art business models enabling the supply chain to be prepared for unforeseen events, react to disruptions and recover from them while remaining operational at the desired level (resilience, (Kamalahmadi & Parast, 2016)) that will transform the supply chain towards Supply Chain 4.0 incorporating flexibility and adaptability in the processes and across all stages.

Currently, the rapid technological advancements consist the enablers and play a pivotal role towards achieving resilience in supply chains by answering the existing challenges or the ones to be. Leveraging digital technologies or innovation practices such as circular supply chains, enhances the strategic management of the supply chain. Digitalization is crucial as it defines the business approaches of the supply chain, while technology integration consist a strategic imperative for companies to drive the market. For example, visibility and transparency of supply chain processes with exploiting Internet of Things (IoT) technology ensures minimization of disruptions, optimization of inventory management and timely delivery of products.

Although digitalization presents a number of benefits such as cost reduction and efficiency, there are challenges and obstacles that companies face such as obstacles in the technology integration or adoption either due to technical issues or the final acceptance of the potential advantages it offers by high-level management. The main problem this study discusses is the strategic enhancement of the supply chain management by integrating state-of-the-art technologies and innovation practices.

The primary objectives are:

1. Explore Key technologies and Innovation Practices for enhancement of the strategic supply chain management.
2. Identification of Key Drivers. Define the key drivers that push a company towards digitalizing its supply chain.
3. Define the strategic importance of Key Drivers in the Supply Chain Management.
4. Key Drivers and Technologies in the case study.

1.4 Thesis Outline

The thesis consists of seven main sections, namely:

Section 1 in which an overview of the supply chain is presented, the problem is stated and the significance of the study is defined.

Section 2 describes the traditional supply chain and develops the emerging technologies and innovation practices in supply chain leading to Supply Chain 4.0.

Section 3 defines the Methodology Framework and the related surveys of the thesis.

Section 4 develops the Key Factors that lead the supply chain digitalization and presents the results of DEMATEL method.

Section 5 describes the case study pathway towards digitalization of the supply chain.

Section 6 discusses the results of the surveys.

Section 7 presents the Conclusion.

The last section 8 presents the Bibliography used to complete the thesis, while the survey results are illustrated in Appendixes A and B.

2 Supply Chain Innovation

Supply Chain Management can be characterized as a fast-growing field, especially in last years with many unexpected events and disruptions taking place, or the advent of technology supporting the streamlining of the various processes. Upgrading from the traditional methods of mainly having limited access to technologies and manually manage processes to state-of-the-art technologies such as artificial intelligence (AI), Internet of Things (IoT), blockchain, Augmented Reality (AR) and more, the supply chain is constantly transforming.

2.1 Traditional Supply Chain

As previously mentioned the supply chain is a network of individuals and companies that are involved in creating a product which will be delivered to the consumer. Every industry has its own supply chains, nonetheless irrelevant of the sector the business is, the supply chain processes can be categorized in five main groups (Spooner, 2024) (*Brief Overview of Supply Chain Management Systems and Supply Chain Resilience*).

- Planning. The planning stage is crucial in the chain, setting the foundation for the entire project by determining resources, timelines, and budgets. It involves detailed forecasting, scheduling, and risk assessment to identify and address potential issues, such as labor shortages or material availability. Contingency plans are created to handle unforeseen challenges, and sustainability is considered in sourcing and delivery processes.
- Procurement/Sourcing Raw Materials. The sourcing stage in the supply chain involves identifying and procuring raw materials. Success depends on securing quality materials at competitive prices while ensuring suppliers meet ethical and environmental standards. The process is ongoing, requiring regular evaluations to maintain material quality and timely delivery while managing risks like market fluctuations and shortages.
- Manufacturing. The manufacturing stage involves transforming raw materials into products. The goal is to produce high-quality products efficiently while adhering to safety and environmental standards. This includes tasks like creating pre-assembled parts or preparing materials. Effective coordination with subcontractors, suppliers, and adherence to health and safety regulations are also critical for success.
- Delivery & Logistics. The delivery stage involves transporting products, requiring careful planning and execution to ensure timely and safe delivery. Logistics complexity is high, as products of varying sizes and sensitivities must be transported across different distances
- Returns. Establishing a system to take back unwanted or defective products from customers. The firm may also return excess or expired raw materials back to the vendors or suppliers.

The above groups include different steps/stages (sourcing raw materials, manufacture products, transporting them and distributing them to consumers (Chopra & Meindl, 2016) (Christopher, 2016)) for which a traditional supply chain structure is illustrated in Figure 3. As it is presented the flow of the materials is one way from the supplier to the customer, while the information later in reverse. This is a rigid structure from which the flexibility and agility is absent (Deshmukh & Vasudevan, 2014).

1. The supplier provides the raw material.
2. The manufacturer converts the raw material into finished products.
3. The wholesaler or otherwise could be the distribution center stores the finished products in warehouses until they are ready to be distributed. These centers can be located in regional hubs.
4. The retailers sell the finished products to the end consumers.
5. The consumers are the final stage who purchases the product.

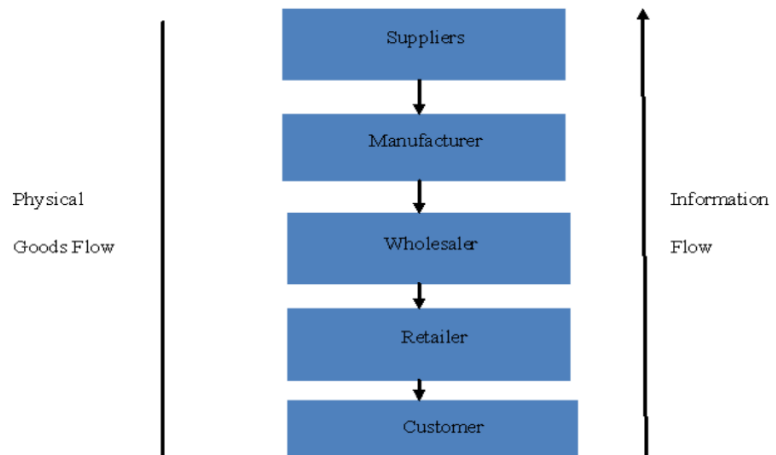


Figure 3: Traditional Supply Chain Structure (Deshmukh & Vasudevan, 2014).

All the above activities are sequential, coordinated and “integrated” in a flow line known as Supply Chain Management. The objective of supply chain management is to synchronise and consolidate all the activities across the supply chain, with the ultimate aim of achieving a cohesive and efficient process (Cao & Jiang, 2021). Nonetheless, although each stage is linked, there is no understanding of each other status (lack of transparency).

However, the concept of the supply chain at the early years was defined as a one-way manufacturing process (linear) centered around the procurement of raw material to make the final product lacking the flexibility to adapt to changes in consumer demand or unexpected disruptions in supply, while also not attributing the necessary importance to the ecological aspect. Furthermore, traditional supply chains tend to operate with minimal technological integration. Operations like inventory management, order fulfillment, and shipment tracking often rely on manual processes, spreadsheets, or legacy systems, when each supply chain stage operates somewhat independently with limited integration among them resulting in miscommunications, delays and unnecessary costs (Stefan Schrauf, 2016). Although, businesses have exploited the traditional supply chain model for many decades (one way process), in modern times a number of challenges have been arisen that require the strategic upgrade of the supply chain. The operational and competitive standing of a business on the market depends on the resilience of its supply chain (Birkie & Trucco, 2020), thus it is important for businesses to transform their operations to ensure adaptability in the new rapidly changing environment. These changes refer not so much to the transformation of the different supply chain steps, but to incorporating the resilience and sustainability aspect in the already existing structure, optimizing the supply chain management.

2.2 Emerging technologies

A number of technologies have emerged in recent years that aspire to drive the transformation of the supply chain. They are addressing not only individual stages, but also the supply chain as a whole—revolutionizing traditional processes and enabling a shift toward faster, more transparent, and more resilient operations. Table 1 presents 8 different

disruptive technologies that aim in transforming the supply chain. These technologies are described in details in sections S2.2.1 – S2.2.8.

Table 1: Emerging technologies and their impact.

Technology	Short Description	Area of Application	References
Artificial Intelligence (S2.2.1)	Technologies that support predictions and forecasting.	Demand & Forecasting, process optimization, inventory & warehouse management	(Chen κ.ά., 2024; Niraj C., 2021; Nsiong Louis Eyo-Udo, 2024; Singh et al., 2020)
Cloud computing (S2.2.2)	Technologies that enable shared data storage, computation, applications, and services.	Visibility and real-time data access, collaboration, scalability and flexibility, process optimization	(Cámara et al., 2015; Goswami & Behera, 2021; Lin & Lin, 2019; Yenugula et al., 2023)
Internet of Things (S2.2.3)	A network of physical objects is embedded with technologies, such as sensors, to produce, process, and exchange data.	Visibility and tracking, predictive maintenance, inventory management	(Ben-Daya et al., 2019; Nozari et al., 2021; Sun et al., 2022; Xia & Liu, 2021)
RFIDs & Bar-coding (S2.2.4)	Technologies that support tracking of products	Inventory management, real-time tracking, visibility	(Tan & Sidhu, 2022; L. D. Xu, 2011)
Big Data (S2.2.5)	Technologies that enable the capture, manipulation, and analysis of large, diversified amounts of data.	Decision-making, forecasting, process optimization, visibility, risk management	(Bag et al., 2020; Hazen et al., 2016; Maheshwari et al., 2021a)
Robotics (S2.2.6)	Technologies that provide a network of self-conducting activities and processes	Process Optimization, automation, scalability & flexibility	(Joseph Fitzgerald, 2017; Mohan Banur et al., 2024; Rainer Jr. et al., 2025)
Blockchain (S2.2.7)	Technology platform that can store and exchange digital content among participants.	Transparency, security, traceability, efficiency	(S. A. Khan et al., 2022; Moosavi et al., 2021; P. Xu et al., 2021)
Augmented reality (S2.2.8)	Technology which superimpose the virtual with the physical world.	Warehouse operations optimization, training & upskilling, inventory management	(Iwona Adamska, 2023; OPSdesign, 2024; Overby, 2019; Rejeb et al., 2021)

These technologies create a fully connected and adaptive supply chain ecosystem able easily adjust to fluctuations in supply, demand, and market trends. In this way, companies are not merely optimizing individual links in the chain, but they are addressing the supply chain as a holistic ecosystem, investing in end-to-end visibility, resilience, and customer-centric innovation. The result is an agile, collaborative network that is poised to meet the challenges of a rapidly changing global marketplace and deliver value at every stage.

2.2.1 Artificial Intelligence

Artificial intelligence (AI) is one of the most well know technologies and the foremost one that leads the digital transformation of the supply chain and the industry in general. The advent of AI can be characterized as revolutionary, transforming the era of traditional barriers (Nsisong Louis Eyo-Udo, 2024). Although, not a subject of the latest years, only recently the technological advances allowed AI to be applied in a vast set of applications. One of the most important areas for a company is to balance supply and demand. It is essential to forecast the demand in order to calculate the supply. Artificial intelligence can process and analyze data (from various sources, either directly from the manufacturing site or from the supply chain as a whole) to predict the demand trends and provide accurate information for the companies to optimize their material sourcing reducing the accompanied costs of warehousing, transportation and administration (Niraj C., 2021). Crucial in this is the capability to select the most suitable supplier. The optimal supplier can play a critical role on quality, cost and reliability towards efficient supply chain operations (Singh et al., 2020), while integrating AI in the supply chain management, a company sets the pathway towards adopting green supply chain practices, ensuring a degree of sustainability. The use of AI models can lead to optimizing the logistics or transportation routes ensuring improved efficiency and environmentally friendly operations (Chen et al, 2024). Using artificial intelligence (AI) in supply chains can revolutionize the planning, production, management and optimization of supply chain activities. By processing vast amounts of data, predicting trends and performing complex tasks in real time, AI can improve supply chain decision-making and operational efficiency. The company can identify threats and take proactive actions to avoid disruptions that can affect production.

2.2.2 Cloud computing

In order to stay competitive in the market, businesses should manage efficient their processes across the whole chain. Especially, supply chain management entails a large number of different actors and stakeholders that need to have access to various information and data in order for the flow of goods and services to work efficiently. This can encompass functions such as production, transportation, storage and distribution for which an adequate communication and cooperation should exist. Furthermore, in today's era, supply chains can be distributed across different countries which adds an additional complexity. Cloud-based solutions are starting gaining recognition since they can provide transparency, efficiency and flexibility in the supply chain. Cloud computing offers the capability to access data and applications from everywhere, as long as there is an internet connection, centralizing and streamlining supply chain operations. All the information is kept online and is accessible easily (Yenugula et al., 2023). The real-time information exchange supports the decision-making and enhances collaboration which in turn leads to cost reduction, while inefficiencies could easily be identified. Cloud computing brings several benefits such as 1) improved efficiency (Cámara et al., 2015), 2) increased agility – flexibility to scale up/down the

operations and respond quickly to market changes, disruptions and demand, 3) better collaboration – among suppliers, partners and customers regardless of location (Goswami & Behera, 2021; Lin & Lin, 2019), increased transparency – manage efficiently the relationships between different stakeholders, track inventory and transportation, 4) better customer service – improve speed and accuracy leading to customer satisfaction, 5) improved sustainability – optimize supply chain operations, minimizing environmental footprint.

2.2.3 Internet of Things

Internet of Things (IoT) is an interesting concept that aims to enhance efficiency and reduce the cost of the supply chain. It can be described as a network of interrelated devices that connect and exchange data with other IoT devices and the cloud. These devices could be sensors or/and software and the exchanged data can vary from equipment information/data or parameters to environmental factors. IoT has provided the opportunity for real-time monitoring of every step across the supply chain to ensure a seamless and efficient movement of the goods

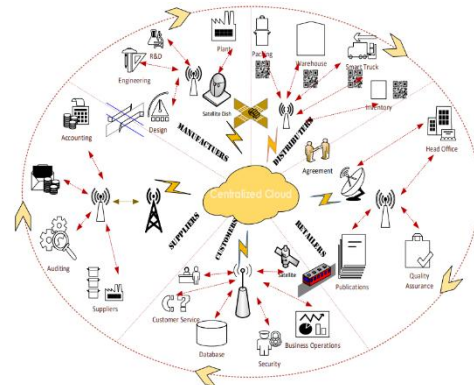


Figure 4: Smart IoT application in supply chain management (Khan et al., 2023)

(and the data) (Ben-Daya et al., 2019), as well as its integration in the supply chain has entailed the following characteristics: (1) intelligent – machine decision making comparatively fast and in real-time (Sun et al., 2022), (2) interconnected – the entire network of IoT can be interconnected, suppliers-manufacturers, distributors (Xia & Liu, 2021), (3) instrumented – increased visibility of IoT supply chains due to integration of devices (Nozari et al., 2021). The IoT goes hand in hand with state-of-the-art technologies and mostly is being used together with some of them, for example RFIDs, middlewares, cloud platforms, etc, in order to support the smart supply chain concept. This, of course, includes some barriers, for example the higher cost of smart gadgets, such as the RFIDs, does not allow the easy access of technology into the open market, nonetheless IoT can lead the supply chain towards flexibility and bring social, economic and environmental benefits.

2.2.4 RFIDs & Bar-coding

RFID technology is a wireless communication that can be used as system inputs for sensing, detecting, identifying, tracking and monitoring. The system has two basic parts: tags and readers. The reader gives off radio waves and gets signals back from the RFID tag, while the tag uses radio waves to communicate its identity and other information (Tan & Sidhu, 2022). RFID has gained considerable attention, especially with the advent of IoT which provides an interconnected network across the supply chain ensuring process efficiency, on-time delivery and accurate transportation. The adoption of RFID-IoT technologies improves operational processes and reduces SCM costs. This is because RFID and other IoT technologies can provide information transparency, product traceability, compatibility, scalability, and flexibility. (L. D. Xu, 2011). Barcode is a similar technology that allows the user to process information as soon as the barcode is scanned (although there are differences with the capabilities of the RFIDs). It provides a reliable and cost-effective way to identify and track products along the different stages. Barcodes also support the different supply

chain processes and offer visibility, accuracy etc, while they can also be used together with the RFID sensors to for a more automated tracking.

2.2.5 Big Data

Companies, in parallel with the advent of technologies and the increasing complexity of the supply chains, have started collecting large amount of data across its different stages (from raw materials sourcing and manufacturing to distribution and end-customer delivery), known as big data. In general, Big Data is described as massive amounts of structured/unstructured data that cannot be managed with traditional methods. Big Data Analytics have the capability to analyse data and share results that generate new insights for improvement. The exploitation of this technology can assist the companies in improving their efficiency, while making decisions faster (Bag et al., 2020; Hazen et al., 2016; Maheshwari et al., 2021a) addressing areas such as faster new product development, better supply chain risk management, better supplier management and development of efficient and robust supply chain designs which in extension lead to the supply chain sustainability.

2.2.6 Robotics

Robotics is one technology that although existed for many years, have recently developed into key concept to support the automation and the efficiency of the supply chain. Robotics can automate a variety of tasks for supply chain management such as minimizing errors, take over repetitive tasks or assist in assembling processes leading to higher efficiency, accuracy, lower costs and improved safety. Mainly, they are used in the the management of the warehouse, however in their arsenal they include different implementations such as automated guided vehicles, collaborative robots or the simple robotic arms (Mohan Banur et al., 2024). The concept of autonomous robot which is capable of decision-making and action taking in respond to changes is an innovation that has started taking its rightful place (*Autonomous Robots and the Future of Supply Chain*, Deloitte.). Especially in logistics, autonomous vehicles and drones have undertaken a significal role in transporting and delivering goods. Although considered an emerging field, robotics have the potentiality to offer cost-effective and environmentally friendly solutions. (Rainer Jr. et al., 2025).

2.2.7 Blockchain

Blockchain is a decentralized, distributed ledger that records transactions ensuring security, and its integration in the supply chain can offer benefits such as transparency, traceability, and efficiency. The supply chains nowadays are characterized of high complexity involving many actors and in different countries which all require accurate information to proceed their workings, bringing certain challenges due to unefficient supply chain integration and sustainability. The use of blockchain technology in supply chains, although still in its early stages, shows significant promise for reshaping how goods and data move across global networks. Blockchain can support all the supply chain stakeholder in creating an integrated ecosystem defined by high security and data interoperability (S. A. Khan et al., 2022; Moosavi et al., 2021; P. Xu et al., 2021)

2.2.8 Augmented Reality

By overlaying digital data on the real world, augmented reality (AR) is transforming supply chain management and improving operational accuracy and efficiency. According to Rejeb et al (Rejeb et al., 2021), AR can be useful in five key areas: manufacturing, sales, outdoor logistics, planning and design, human resource management, and warehousing. AR speeds

up order fulfilment and lowers errors in warehouse operations by enabling hands-free picking through smart glasses, which gives employees real-time visual guidance. For example, DHL's warehouse productivity increased by 15% after implementing AR (Overby, 2019). By superimposing digital data on actual objects, augmented reality helps inventory managers perform accurate and timely inventory checks by enabling real-time stock updates and precise tracking (OPSdesign, 2024). Furthermore, AR offers comprehensive guidance for equipment maintenance, which lowers downtime and enhances safety. The advantages of AR, such as improved accuracy, training, and collaboration, make it a disruptive instrument for modern supply chain operations, even despite the presence of barriers like costly initial investment and integration complexity (Iwona Adamska, 2023).

2.3 Innovation Practices in Supply Chain

A well known choice to follow for addressing SC vulnerability is resilience, which can be achieved by implementing a wide range of features. There are quite a few pathways towards resilience with the most prevalent one being (Ivanov, Dolgui, Sokolov, & Ivanova, 2017): (1) building redundancy which includes establishing back up plans, alternatives or having extra resources in case they are needed (for example: maintaining a higher amount of stock or storing raw materials); (2) integrate the flexible aspect in the supply chain to be able to adapt and reconfigure in case of emergencies; (3) impliment agility which refers to quick operating status alterations of the supply chain in a cost-effective way when needed; (4) establish collaborations by working closely with SC partners incorporating transparency and creating strong partnerships for mutual benefit; (5) encompass innovation by digitalizing and transforming the procedures and processes. Additionally, it is important for businesses to establish a set of strategies that generate resilience over its phases: (i) before-disruption, by predicting probable disruptions and developing mitigation methods to reduce the impact (risk identification, strong connections), (ii) during-disruption, acquiring the ability to respond and to recover quickly and efficiently when a disruptive event occurs, (iii) after-disruption, having the ability to recover fast and also strengthen the supply chain resilience to be ready to confront future disruptions (Carissimi, Pratavia, Creazza, Melacini, & Dallari, 2022).

Based on a study from DELOITTE (Camilla Thuge Lund, 2022), the resilient supply chain (a resilient organization) is based in four pillars.

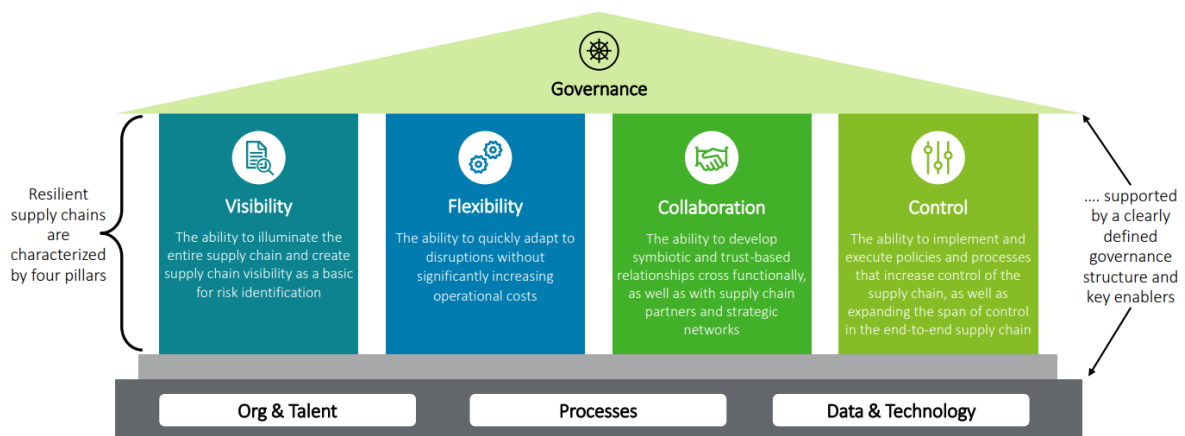


Figure 5: Key components of a resilient operation (Camilla Thuge Lund, 2022).

- **Visibility:** The ability to illuminate the entire supply chain and create supply chain visibility as a basic for risk identification.
- **Flexibility:** The ability to quickly adapt to disruptions without significant increasing operational costs.
- **Collaboration:** The ability to develop symbiotic and trust-based relationships cross functionally, as well as with supply chain partners and strategic networks.
- **Control:** The ability to implement and execute policies and processes that increase the control of the supply chain, as well as expanding the span of control in the end-to-end supply chain.

Furthermore, in order to successfully integrate the key elements in the SC and for a business to build a robust and resilient SC, it is crucial the company to implement effective governance structures, as well as key enablers. The Key Enablers can be defined in three categories: Organization & Talent, Processes, Data & Technology. The first category is addressed to people. The organization should foster an innovation culture that is based on sustainability practices and transfer these insights to its employees raising awareness on the benefits that it brings. Accordingly, it should integrate in its workforce, the relevant roles and determine corresponding responsibilities ensuring the smooth integration in the business processes as well as its culture. In order to achieve these, it is necessary to follow a structured plan and policies to transform the already established processes and procedures that build the supply chain. With regards to this, adequate KPIs should be defined and monitored to check progress and corresponding actions should be followed to optimize them. Lastly, technology plays an essential role in enabling the sustainability in the supply chain and implementing the circular economy concept by facilitating various offerings and benefits.

Nonetheless, even before the advance of technology the latest years, the supply chain stakeholders were researching ways that could build up resilience and develop a sustainable supply chain that could cope with disruptions. The most popular ones based on INFOSYS¹ being :

- i. storing inventory and capacity buffers, so that in case of a material scarcity to keep the production up
- ii. establishing diverse manufacturing ecosystems and incorporating in the processes tactics such as
 - a. multisourcing (procuring materials from multiple suppliers to reduce dependency on a single source)
 - b. nearshoring (reducing geographical dependence by sourcing materials from local or nearby locations)
 - c. multiple shipping carriers (to distribute risk and maintain a smooth flow of goods, even during unexpected disruptions)
- iii. standardize the processes, products and facilities by integrating interchangeable and generic components and similar designs to quickly respond to disruptions by reallocating resources
- iv. integrating technology (sub-section S2.3 refers to technologies and their impact in the supply chain)
- v. strategic planning which can be further detailed in a number of strategies such as implementing risk management and contingency planning measures,

¹ <https://www.infosysbpm.com/blogs/supply-chain/6-strategies-for-a-more-resilient-supply-chain.html>

developing strategic partnerships and relationships with supply chain stakeholders or adopting supply chain models designed to adjust to changing market conditions (e.g. lean manufacturing)

In recent years, the Circular Economy (CE) concept is gaining ground and many businesses have set their focus on trying to implement circular supply chains and the relevant business processes. According to European Union, circular economy is:

A circular economy is a system which maintains the value of products, materials and resources in the economy for as long as possible, and minimises the generation of waste. This means a system where products are reused, repaired, remanufactured or recycled (Circular Economy - EUR-Lex)

In simple words, CE is a model that aspires to extend the lifecycle of the products and reduce waste. This is a transition from the traditional and linear economic model to circular ones, by thinking how resources are used throughout the supply chain, from raw material sourcing to product design, manufacturing to the customer. Already from 2015, the European Commission has started adopting and developing plans that will set the Europe pathway towards circular practices. From then on and until October of 2023, many steps were taken by adopting the European Green Deal, announcing measures and updating the established green deal plans, as well as revising the circular economy monitoring framework (*Circular Economy Action Plan - European Commission*). The businesses are being called to review their processes, enforce new regulations and design products with sustainability in mind. Circularity in supply chains not only lead to a sustainable process benefiting businesses, but also society, by reducing carbon footprint, providing new jobs as well as clearer ecosystems. Below, a schema of a circular supply chain is presented.



Figure 6: Circular supply chain schema (Circular Supply Chain Management, 2023).

Circular economy is supported by the R’ strategies, which are approaches that a company could encompass to reduce waste, minimize resource consumption and extend product lifecycle. Based on the literature (Alivojvodic & Kokalj, 2024; European Commission. Directorate General for Research and Innovation., 2020; Larae Malooly, 2023), there are ten main strategies.

R0	Refuse	Make product redundant by abandoning its function or by offering the same function by a radically different (e.g. digital) product or service
R1	Rethink	Make product use more intensive (e.g. through product-as-a service, reuse and sharing models or by putting multi-functional products on the market)
R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
R3	Re-use	Re-use of a product which is still in good condition and fulfils its original function (and is not waste) for the same purpose for which it was conceived
R4	Repair	Repair and maintenance of defective product so it can be used with its original function
R5	Refurbish	Restore an old product and bring it up to date (to specified quality level)
R6	Remanufacture	Use parts of a discarded product in a new product with the same function (and as-new-condition)
R7	Repurpose	Use a redundant product or its parts in a new product with different function
R8	Recycle	Recover materials from waste to be reprocessed into new products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations
R9	Recover	Recover extends beyond recycling by encouraging the repeated use of products and materials. It focuses on extracting energy or raw materials from waste that cannot be reused, repurposed, or recycled.

The R strategy implementation is facilitated by the implementation of technology enablers that can support the relevant aims. For example by developing product designs to achieve a longer lifecycle or monitoring products and defining next steps in the supply/value chain such as remanufacturing if the components of a product can be reused (in the same or other supply chain).

2.4 Supply Chain 4.0

Supply Chain 4.0 represents a transformative shift in supply chain management referring to the integration of advanced cutting-edge digital technologies that revolutionize traditional practices. Crucial building block of the digital supply chain is Industry 4.0 which serves as the technological backbone driving the supply chain’s evolution (Huang et al., 2023). The defining characteristics of Supply Chain 4.0 are the deployment of smart,

interconnected, and automated systems that enable greater agility, efficiency, and visibility, thereby allowing businesses to respond more swiftly and precisely to market dynamics.

Recent data highlights the widespread adoption of these technologies. According to the latest survey co-conducted by the *Council of Supply Chain Management Professionals* and *ToolsGroup (Digital SC Planning)*, 93% of companies say they are actively engaged in the process of digitalising their supply chains. This transformation has also spurred as result of global disruptions that affected the supply chains such as COVID19 which first exposed the vulnerability of supply chains (Sherman, 2020) and the Ukrainian War (Tsang et al., 2024). These events underscored the urgent need for supply chains to evolve from rigid, linear models to more flexible, dynamic structures capable of mitigating risks and adapting to unforeseen challenges.

The technological advancements driving the shift (mentioned in S2.2) are enhancing the supply chain resilience, by transforming its linear structure to a more adaptive, flexible model. These shift enables stakeholders to benefit from increased transparency, visibility and real-time collaboration throughout the supply chain. Digitalization is key in developing an entirely integrated ecosystem from the suppliers of raw materials, components, and parts, to the transporters of those supplies and finished goods, and finally to the customers demanding fulfillment. In this interconnected ecosystem, each participant can access real-time data regarding statuses, needs and challenges of others. to adapt accordingly, while demand and supply will be communicated across the whole chain. This mutual visibility will improve coordination and mitigate risks. The companies will be able to anticipate the disruption, not only react to them, building a resilient and sustainable ecosystem.

Figure 4 illustrates the contrast between the traditional linear supply chain and its digitally-enabled counterpart. While the traditional model operates in a more rigid, one-directional manner, the smart supply chain is inherently more complex. It fosters *bidirectional relationships* at every stage, enabling ongoing dialogue and responsiveness across the entire network. This dynamic structure ensures the *flexibility* needed to meet customer demands efficiently, while maintaining high levels of *agility* and *adaptability* in the face of evolving market conditions.

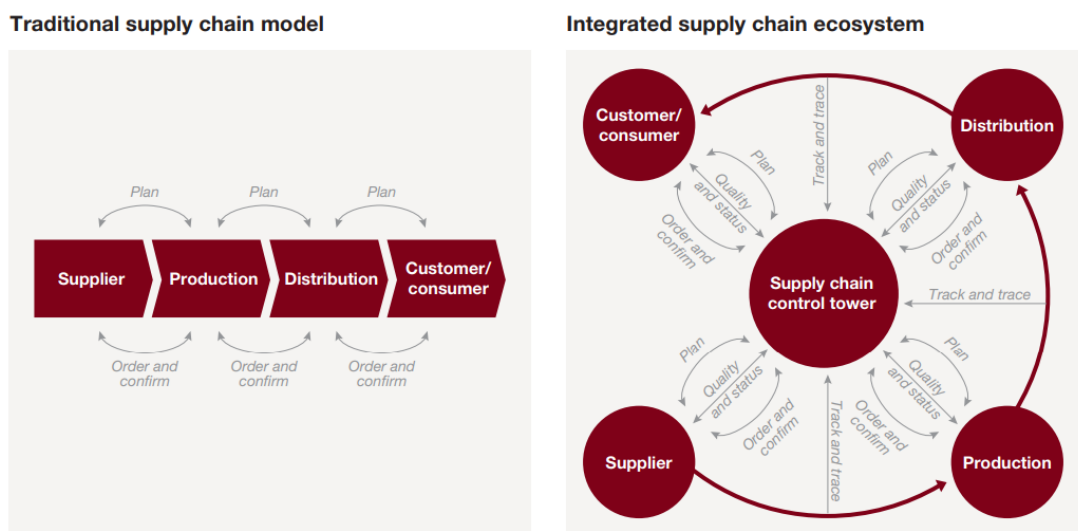


Figure 7: The digitally enabled supply ecosystem vs. traditional linear supply chain (how-digitization-makes-the-supply-chain-more-efficient-pwc-2016.pdf)

This complex model offers a comprehensive view of the supply chain (Transparency), enables seamless information sharing among all supply chain members (Communication), ensures efficient collaboration (Collaboration), offers effective adaptation to customer demands (Flexibility) and provides real-time response on planning and execution level (Responsiveness)(Lee et al., 2024).

These advancements directly contribute to a company’s competitive advantage. Digital technologies have been shown to enhance production efficiency by ensuring seamless and timely information exchange (Saryatmo & Sukhotu, 2021). Moreover, the financial benefits of digitalization are substantial, as it plays a pivotal role in reducing operational costs and improving profit margins (AlMulhim, 2021) (Cook, 2020). Additionally, improved customer understanding, paired with faster delivery times, allows businesses to better meet customer needs and expectations, thereby strengthening their market position (Agrawal & Narain, 2018).

3 Methodology Framework

Section 3 describes the methodology that was followed for conducting the research and completing the master thesis. Initially, the methodology was defined based on the aim of the study. The literature review approach was selected to gather the relevant information from academic articles, industry reports, and etc. Following the literature review a data analysis was conducted to draw conclusions. These conclusions were used to derive the key driving factors for the supply chain digitalization as well as develop the questionnaire for the in-depth analysis of a case study.

Therefore, two were the main stages in order to reach the final results. Firstly, an extensive literature review was conducted. The literature review is an important part to explore and understand better the study topic. Secondly, based on the findings of the literature review, questionnaires were developed to collect all the necessary data and information to successfully reach a result.

3.1 Literature review

A literature review is an important component of a research study. This approach entails a structured way to identify, evaluate and synthesize existing research on a specific topic, especially important when exploring novel topics.

The first step was to define the research question. In this case, the key driving factors of the supply chain digitalization, as well as information to derive the supply chain digitalization stage of a business were the key elements. To conduct the analysis, a search on the Scopus database was conducted using the following query: (TITLE-ABS-KEY ("supply chain") AND TITLE-ABS-KEY (digitization) AND TITLE-ABS-KEY (manufacturing)). The search returned 190 results. In order to extend our information base, a similar study was conducted on Google Scholar, providing the same keywords, while setting the year date from 2019 to ensure that we include the latest developments. This search returned a high number of papers, however to minimize time-consumption and ensure efficiency, we applied an initial screening procedure based on the inclusion and exclusion criteria (relevance, credibility, recency) we had set. The criteria as well as the selection process had defined before conducting the initial search. Furthermore, all the papers non written in English were excluded to ensure accessibility and consistency in the assessment procedure. Following the previous steps, we screened the remaining papers (both from Scopus and Google Scholar) by their titles and abstracts to ensure relevance with the master thesis' topic. The screening resulted in a total number of 100 papers, which were the building blocks of the master thesis. During this step, there were a few papers that were excluded due to lack of relevance, as well as works which weren't accessible. Finally, the data acquired from the selected papers were used to develop the following surveys. Moreover, reports from acknowledged institutes and organizations were taken into consideration to support our results.

3.2 Surveys

Based on the literature review, two surveys were developed. The first one addressed the key factors for supply chain digitalization and the second the in-depth analysis of the digitalization status of a company in the plastic sector.

3.2.1 DEMATEL technique

First developed by the Geneva Research Centre of the Battelle Memorial Institute, the DEMATEL technique or the Decision making trial and evaluation laboratory, aims in visualizing the structure of complicated casual relationships through matrixes of digraphs. DEMATEL is a structural modelling approach to analyze the cause and effect relationships among differencnt components of a system. It presents the interdependence among factors and reflect the effect one has on the other. By quantifying the component interactions, the researcher can distinguish between Cause factors and Effect factors (Gabus Andre, 1972). As it is described by Si et al. (Si et al., 2018), we have the following steps:

First step

The first stage refers to developing the Direct-Relation Matrix. Therefore, the assessment of the relationships between n factors $F = \{F_1, F_2, \dots, F_n\}$ in a system, consiering that I experts have provided inputs $E = \{E_1, E_2, \dots, E_i\}$ have to be realized. The I group is asked to indicate the influence that the Factor F_i has on Factor F_j using an integrer scale of “no influence (0),” “low influence (1),” “medium influence (2),” “high influence (3),” and “very high influence (4), thus the direct influence matrix can be produced (e.g. $Z_k = [z_{ij}^k]_{n \times n}$). All the diagonal elements are equal to zero. To aggregate all the experts opinion, the matrix should be divided by the number of experts’ opinion.

$$z_{ij} = \frac{1}{l} \sum_{k=1}^l z_{ij}^k, i, j = 1, 2, \dots, n \quad (1)$$

Seond step

Following the direct influence matrix, the normalized one should be developed. This can be achieved by using the

$$X = \frac{Z}{s} \quad (2)$$

$$s = \max(\max_{l \leq i \leq n} \sum_{j=1}^n z_{ij} \max_{l \leq i \leq n} \sum_{i=1}^n z_{ij}) \quad (3)$$

All the elements in the maxri X are complying with the $0 \leq x_{ij} \leq 1, 0 \leq \sum_{j=1}^n x_{ij} \leq 1$, and atl least on i such that $\sum_{j=1}^n z_{ij} \leq s$.

Thrid step

The next stage is constructing the total influence matrix, based on the

$$T = X (I - X)^{-1} \quad (4),$$

where I is the identity matrix.

Fourth step

The last step in calculating the R and C values, which are the sum of rows and the sum of columns from the total influence matrix. This will lead to the “Prominence”, the R+C, which illustrates the strength of influence that each factor gives or receives. The R-C vector, “Relation” shows the effect that a factor contributes. If the R-C is positive, then the factor is considered a Cause and has an effect on the other factors, else, if the R-C is negative then the factor is influenced more by the other factors and is considered an Effect.

In order to implement the DEMATEL technique, we have developed a survey (Appendix A) and distributed it to supply chain stakeholders. The survey was consisted of a number of questions that aims in investigating the interdependency of the factors amongst them. The possible answers of the questions are presented below.

Each question could be answered in a five degree scale as depicted below and corresponded to a value from 0 to 4:

Value	Correlation degree	Color coded
0	No correlation/effect	
1	Very low correlation/effect	
2	Low correlation/effect	
3	High correlation/effect	
4	Very High correlation/effect	

3.2.2 Single case study approach

The aim of the single case study approach is to investigate the supply chain digitalization pathway of a company in the timeframe of 10 years prior to 5 years ahead. In this direction, we have divided 3 time periods:

- 10 years prior supply chain digitalization level
- Present supply chain digitalization level
- Future (5 years) supply chain digitalization level

For each time period, and based on questions derived from Section 2, we have attempted to collaborate with a company to record information on the technologies and practices they have implemented over the years to upgrade their supply chain. In this direction, we have come in contact with a medium company (of 90 people personnel) in the plastic manufacturing sector. The company is based in Evros, Greece, while its client portfolio is extended to Europe, Australia, Egypt and Israel. Furthermore, its supplier base is in Europe and Asia.

For a better understanding of the case study and start building on the investigation, an interview/workshop was conducted with the company. The aim of the interview was to discuss the supply chain state of the company for the different time periods and derive information that will support the building of the use case. During the interview, notes were being taken for the different sections which later were enriched with the oral information that the company has provided. The overall duration of the interview was 2 hours during

detailed information on technologies, aims and aspirations of the company were provided. To further validate our findings and understanding of the case study interview, the questionnaire completed with the information derived from the interview was shared to the company in order to ensure the validity of the results. After checking the recorded information, the company returned the questionnaire with notes where and if needed.

3.3 Study limitations

This study involved the research on two different main subjects. The first one being the investigation of the key drivers that lead the digitalization of the supply chains, while the second was the in-depth analysis of the digitalization degree of a business in the plastic field.

Regarding the first study, one of the limitations is the small size of the sample. An amount of only 10 respondents may not be able to capture the full diversity of perspectives for a comprehensive analysis. However, Paton (Patton, 2014) mentions that small samples such as 10 responses, can provide insights in a qualitative case study research. This is further justified from Creswell and Poth (John Creswell & Cheryl Poth, 2018), who they emphasize that small sample sizes in a qualitative research can provide depth and insights. It is also mentioned in the Sage Encyclopedia of Qualitative Research Methods (Given, 2008) and by Hertzog (Hertzog, 2008) that a size of 10 can be sufficient to identify trends and patterns as well as test feasibility. Also, as DEMATEL relies heavily on expert evaluations to determine the relationships between factors, the participation of only one person from each company can introduce a degree of subjectivity, since there may be differences in the perspectives of different persons, even in the same company. To address this, the questionnaire was shared to supply expert employees, asked for similar (level) positions in the companies, as well as the different company type was sought to address the diversified perspectives.

As regards the second study, the research was focused on one company. The participation of only one person may provide a limited degree of perspective and not capture accurately the digitalization effort of the company. To have more accurate results, the person contacted (interview) was the facility production manager having an overview of all the processes, from raw material acquisition to the value chain (e.g production, transport) to the final client. Furthermore, to have accurate and validated results the completed questionnaire was shared back to the company, and was distributed for validation also to the CEO (a higher level) and the production managers (lower level) of the different departments.

4 Key Drivers towards sustainability and resilience

4.1 Challenges of the supply chain management

As already mentioned, supply chain is a large network of different stakeholders that need to coordinate among them in order to manufacture the final product and distribute it to the consumer. This flow optimization which can entail not only the product as the product, but also information and finance (that come together with the item) many times comes against challenges challenges. These challenges can refer to the supply chain as a whole, for example, lack of proper communication between the different stages of the supply chain, but also to individual stages of the supply chain, such as the integration of a forecasting system in the manufacturing facility to predict consumer demand and lead to accurate production.

Starting from the simplest supply chain model, the traditional linear model is characterized as a forward-product value chain in which the stakeholders (e.g. suppliers, producers, distribution service and consumers) are linked in a straight sequential material flow, while the final product, after the end of its life, is discarded. The traditional linear supply chains are increasingly unsustainable due to continuously resource depletion (Banico, 2024), as well as due to globalization. As the industrial revolution marked the era of unlimited production, providing the market power in the hands of the consumers, the companies looked for new markets and resources aiming in economies of scale adding complexity to the supply chain operations (Awad & Nassar, 2010). The challenges that the supply chain is up against:

- The limited visibility and transparency between the different stages constraints the ability of the supply chain to respond fast to disruptions and changes in consumer demands leading many times to overproduction/overstocking or stockouts (Harris, 2023),
- The vulnerability to disruptions of the supply chain allows for delays due to downtimes at the different stages in case of one,
- The absence of flexibility and agility adds barriers to quick adaptation to market changes or disruptions (EY, 2023),
- Regulations and policies, such as the green deal, can disrupt supply chain operations, necessitating quick adaptations to ensure standard compliance,
- Environmental sustainability is increasingly taking its place in the supply chain operations, which are called upon to implement sustainable practices and reduce their carbon footprints,

have led the organizations to start exploring pathways to integrate the sustainable, resilience and circular aspect to their supply chains, thus addressing the challenges that the traditional supply chain model faces. The technologies and the innovation practices described in section 2 facilitate the transition to the new supply chain model and a strategic supply chain management, however this change also carries challenges, mainly for the new business model implementation. Building on the circular model that promotes resilience and sustainability, Bressanelli et al (Bressanelli et al., 2019) identified 24 challenges about redesigning the supply chain according to circular economy principles, categorizing them in 7 categories, while Roy et al. (Roy et al., 2022) describes 20 barriers/challenges. Taking also into consideration other supply chain strategies such as multi/near-sourcing, risk

management, technology integration, cultural changes, etc., we have identified a number of challenges/barriers (Dubey κ.ά., 2017; Susan Lund, 2020; Tang, 2006). In the table below, we present the challenges that are more relevant with the supply chain management as well as technological integration towards Supply Chain 4.0.

Table 2: Challenges for integrating sustainability and resilience in the supply chain.

Challenge	Short Description
Financial constraints	Measures like dual sourcing, capacity buffers, and safety stock often require capital expenditures.
Organizational blocks	Lack of cross-functional alignment.
Regulatory and geopolitical complexities	Frequent changes in trade policies or tariffs can invalidate long-term sourcing strategies and undermine multi-sourcing investments.
Skill Gap	Lack of expertise in the supply chain 4.0 model.
Product Complexity	The increased complexity of a manufactured product can result in difficulties to recover or recycle it.
Mass customization	Customized products can pose difficulties in reusing or remanufacturing.
Lack of standards	Lack of standards and framework about circular processes.
Logistics, transportation and infrastructure	The recovery of products increases the cost of logistics, transportation.
Transparency, visibility	Supply chain stakeholders aren't in favor of sharing sensitive information, as well as there may be a lack of the corresponding digital infrastructure.
Product tracking and traceability	There aren't suitable mechanisms for tracking and tracing across the supply chain.
Cannibalisation	The new circular products can have an extended life-cycle affecting company revenues
Culture aspect	Company internal resistance to change
Data privacy and security	Concerns about privacy and data security

Nonetheless, irregardless of the challenges that the supply chain redesign encompasses, companies identify the benefits that a robust and resilient supply chain brings (1) Reduced risk, (2) improved customer satisfaction, (3) cost savings, (4) enhanced reputation and (5) business continuity & efficiency.

4.2 Key drives and their analysis

Based on the literature review, we have used in total 32 papers and 4 European Acts/Regulations to derive the following Key Drivers. The papers were studied to find trends and patterns that result in orienting the firms towards supply chain digitalization.

Table 3: The Key Drivers and relevant references.

Key Drivers	References
Demand for improved efficiency, cost and waste reduction	(Amejwal et al., 2022; T. Khan et al., 2024; Menezes & Carpitella, 2023; Winkler & Kaluza, 2006)

Customer Expectation	(Adam et al., 2020; Boone et al., 2019; Tien et al., 2020)
Need for real-time visibility and transparency, collaboration and communication across the supply chain	(Brun et al., 2020a; Garcia-Torres et al., 2024; McGrath et al., 2021; Pal, 2023)
Innovation potential and digital capabilities	(Saravanan et al., 2022; Ullah et al., 2024; Wang et al., 2025)
Supply chain Sustainability and Environment	(Jadhav et al., 2019; Li et al., 2024; Taghikhah et al., 2019)
Regulatory requirements for traceability and compliance	(Kunhahamed & Rajak, 2023) Acts: Green Deal Act, Net Zero Industry Act, Ecodesign for Sustainable Products Regulation, Critical Raw Material Act
Enhanced supply chain resilience (risk management) and agility (flexibility)	(Jones, 2023; Kazancoglu et al., 2022; Kumar et al., 2020; Schleper et al., 2021; Shen et al., 2021; Wang et al., 2025)
Increasing supply chain complexity due to globalization	(Brun et al., 2020a; Jones, 2023; Serdarasan, 2013)
Growing importance of data-driven decision-making	(Awan et al., 2021; Maheshwari et al., 2021a; Redžeb, 2024; Shashwat Agrawal et al., 2023)
Need for better demand forecasting, inventory optimization and process automation	(Albayrak Ünal et al., 2023; Tsintotas et al., 2025)

4.2.1 The key factor survey

Our investigation and study recognized ten main driving factors and based on them, a questionnaire was developed (Appendix A). The focus of the questionnaire was to understand the interdependency of each factor with the other applying the DEMATEL technique (described in S3.2.1). The driving factors are presented briefly below, while more information on them can be found in the following sections S4.2.1 – S4.2.10.

- F1: Demand for improved efficiency, cost and waste reduction
- F2: Customer expectations
- F3: Need for real-time visibility and transparency, collaboration and communication across the supply chain
- F4: Innovation potential and digital capabilities
- F5: Supply Chain Sustainability and Environment
- F6: Regulatory requirements for traceability and compliance
- F7: Enhanced supply chain resilience (risk management) and agility (flexibility)
- F8: Increasing supply chain complexity due to globalization
- F9: Growing importance of data-driven decision-making
- F10: Need for better demand forecasting, inventory optimization and process automation

The survey was referred to experts on supply chains. Each participant was called upon to also provide information such as 1) the company name, 2) the company place, 3) the company size and 4) the company type (manufacturer, logistics, transportation, supplier, retailer, distributor, service provider, technology provider, other). However, due to confidentiality reasons, the companies' names won't be disclosed in the Master thesis.

The questions are presented below:

1. How does the F1 factor *"Demand for improved efficiency, cost and waste reduction"* correlates/affects the rest of the factors.
2. How does the F2 factor *"Customer expectations"* correlates/affects the rest of the factors.
3. How does the F3 factor *"Need for real-time visibility and transparency, collaboration and communication across the supply chain"* correlates/affects the rest of the factors.
4. How does the F4 factor *"Innovation potential and digital capabilities"* correlates/affects the rest of the factors.
5. How does the F5 factor *"Supply Chain Sustainability and Environment"* correlates/affects the rest of the factors.
6. How does the F6 factor *"Regulatory requirements for traceability and compliance"* correlates/affects the rest of the factors.
7. How does the F7 factor *"Enhanced supply chain resilience (risk management) and agility (flexibility)"* correlates/affects the rest of the factors.
8. How does the F8 factor *"Increasing supply chain complexity due to globalization"* correlates/affects the rest of the factors.
9. How does the F9 factor *"Growing importance of data-driven decision-making"* correlates/affects the rest of the factors.
10. How does the F10 factor *"Need for better demand forecasting, inventory optimization and process automation"* correlates/affects the rest of the factors.

4.2.2 Demand for improved efficiency, cost and waste reduction

The industrial revolution in the previous century that transformed the production lines, and Industry 4.0 that have introduced new technologies in the manufacturing processes, have led to a turbulent and competitive landscape. These conditions of rising competitiveness and economic pressure push for the adoption of solutions that should allow manufacturers to gain insights and identify inefficiencies into their supply chain (Menezes & Carpitella, 2023). The conventional supply chain model emphasized cost reduction and efficiency enhancement, however efficiency, cost and waste are interdependent concepts. By implementing sustainable practices and waste management strategies (minimizing the use of excess material and improve resource efficiency), an organization can save costs and enhance productivity (T. Khan et al., 2024). Furthermore, improving waste reduction has cost-effective impact in the supply chain offering profitable advantages in terms of environmental cost and position, which can in extension strengthen customer loyalty, and be beneficial for a favourable market position (Winkler & Kaluza, 2006). Therefore, enterprises continuously seek new ways to enhance operational efficiency and reduce waste, thus leading to substantial cost savings and reduced environmental impact. The implementation of lean manufacturing tools in cooperation with state-of-the-art technologies such as Internet of Things, Artificial Intelligence, Cloud computing, Big Data, etc, support and facilitate the need of the organizations to be efficient in their production flows, end-to-

end from raw material to final customer, reducing lead times and, replacing downtimes and ensuring on-time delivery (Amejwal et al., 2022).

4.2.3 Customer expectation

In today's markets, consumers are overwhelmed with a high number of products, offering the same functionality. The high competitiveness that defines the market environment has shaped the customers' demand not only to high quality products but also to transparency (the journey of the product) and sustainability (environmental impact) in the supply chain, thus consumers are increasingly demanding, difficult to keep and costly to replace, while meeting their evolving expectations (Tien et al., 2020). Additionally, customers expect faster delivery times and personalized services, while the shift from traditional marketing to modern with the use of digital marketing, social media and e-commerce platforms has influenced their buying behaviour (Adam et al., 2020). Furthermore, the better a business appreciates a customer's behavior and buying habits the more accurate will appreciate the production requirements and address the consumer demand (Boone et al., 2019), therefore satisfying the market needs is essential to gain a competitive advantage. Nowadays, it is crucial for businesses to foster and nurture consumer loyalty which will lead to repeated purchases. To answer this call, firms are investing in the use of new technologies such as artificial intelligence, blockchain and cloud computing to improve order satisfaction, develop faster new products and launch them in the market, lower cost and offer better services.

4.2.4 Need for real-time visibility and transparency, collaboration and communication across the supply chain

The supply chain network consists of a number of stakeholders along the different stages of the product journey, from raw material to manufacturing to the final consumer, while intermediate steps such as warehousing, transportation and logistics further complicate the supply chain ecosystem. Therefore, there is a growing need to connect all the different stakeholders successfully to enable sustainable and efficient supply chains. Transparency is a critical factor among the different supply chain industries allowing them to trace the product and the flow of goods, ensuring that all the required practices and standards, such as environmental regulations are applied. The information and data exchange enhances the supply chain communication which in turn improves collaboration. Knowledge sharing, resource exchange and efficient engagement are critical factors that answers the increasing complexity of the supply chains. Furthermore, businesses offer product visibility to the consumer enabling real-time monitoring of the goods and the relevant processes building trust and loyalty (Brun et al., 2020a; Garcia-Torres et al., 2024; McGrath et al., 2021). Digitalization of the supply chain and the implementation of the right technologies such as blockchain and cloud computing for efficient and secure information sharing or technologies that enable the tracking of the products (RFID, bar-coding) transform the supply chain management concept forming an interconnected network of assets (Pal, 2023).

4.2.5 Innovation potential and digital capabilities

Following the technological evolution, businesses are trying to keep up with the new trends and grab opportunities for innovation, integrating in their supply chain digital capabilities. As the recent years have vividly illustrated, disruptions (wars, pandemics, natural disasters) have a strong impact on the supply chain, for example, COVID-19 (Saravanan et al., 2022), which showed the vulnerability of the ecosystem. However, digitalization can offer several

benefits such as increased productivity and improved supply chain performance, which in turn have an effect on costs (Ullah et al., 2024). To achieve this, various technologies and innovation practices can be implemented (AI, IoT, Cloud computing, circularity – more on section 2), that affect a number of processes such as demand forecasting, material sourcing, warehousing, etc that provides to businesses the capability not to respond faster, but anticipate future events and be suitable prepared, supporting resilience and sustainability in the supply chains. Organizations that leverage the cutting-edge technologies optimize their operations, streamlining procedures and stay ahead in this competitive era. Firms that invest in digital infrastructures enhance their adaptability to unexpected events, foster innovation vitality withing the network and comply with the environmental requirements (Wang et al., 2025). Therefore, integrating digital capabilities results in operational excellence of the businesses enabling them to remain as leaders sustaining the competitive advantage they had previously build or rise against the competition to claim the market share.

4.2.6 Supply chain Sustainability and Environment

The impact of supply chain sustainability has started the latest years to receive considerable attention. It is important to clarify that the term sustainability refers to environmental issues, however integrates also financial performance and the social aspect (Li et al., 2024). The production of an excess amount of products due to overconsumption and the need for gaining competitive advantage have led the enterprizes to affect negatively the environment. Critical areas such as global warming and the depletion of natural resources drive the firms to rethink their processes and embrace new concepts (Jadhav et al., 2019), expecting to minimize their environmental footprint (CO₂, wastes, energy) (Li et al., 2024; Taghikhah et al., 2019). Moreover, sustainable supply chains are better oriented to mitigate risks associated with resource scarcity, climate change, and regulatory shifts, thereby enhancing long-term business resilience. By implementing green practices and state-of-the art technologies, businesses can embrace the green transition while at the same time support the efficiency of the supply chain operations. A sustainable supply chain adopting aspects such as circularity, and implementing green strategies (the R's, remanufacture, recycle, repurpose, etc – section 2.3), facilitates its position to react quickly to disruptions as well as optimally exploit its resources, with minimal impact. Lastly, the increasing consumer awareness on environmental issues, requiring transparency and environmentally friendly processes, is a critical factor to address, since it can enhance or decrease brand reputation.

4.2.7 Regulatory requirements for traceability and compliance

European Commision has declared a number of regulations and requirements that drive companies to integrate robust traceability and compliance protocols, to ensure strict standards for product safety, environmental protection and ethical sourcing. Climate change and environmental degradation are no longer abstract concepts and tangible threats to Europe and World. Legislative initiatives and European Acts such as the Green Deal Act², Net Zero Industry Act³, the Ecodesign for Sustainable Products Regulation⁴ consist the blocks for Europe's approach to more environmentally sustainable and circular products.

² https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

³ https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

⁴ https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en

Furthermore, the Critical Raw Material Act⁵ reinforces Europe’s direction to secure a sustainable supply of critical raw materials. These standards boosts companies to investigate and adopt new technologies, innovation practices or manufacturing methods. Such methods will not only enable and facilitate the traceability of the product lifecycle, ensuring compliance with the new regulations, but support the firms’ transition to green practices and circularity that allows for flexibility and agility, strengthening their supply chain resilience. Among the latest technologies is blockchain, as one of the main drivers in ensuring traceability, security and trust across different transactions. By enabling the secure exchange and accurate tracking of information and data, blockchain technology is particularly valuable in the context of the Industry 4.0 era, characterized by heightened competition and increasingly complex supply chain interactions. Blockchain technology can take the role of ensuring compliance with the environmental and governmental legislations (Kunhahamed & Rajak, 2023).

4.2.8 Enhanced supply chain resilience (risk management) and agility (flexibility)

Focusing on the latest years, the world had to manage many adversities such as epidemics, natural disasters and wars. These disruptions cause problems (lack of energy, rising costs, etc) and affect the operational efficiency of the supply chain, for which firms should take measures against. Especially, in this competitive era, firms should start investing in developing supply chain resilience to stay ahead in the market race. The globalization has produced risks across the supply chain that a company should proactively address to. The ability to quickly adapt to disruptions is vital for modern supply chains, therefore integrating resilience and innovative technologies enhance both risk management and agility. It is essential for enterprises to adopt risk management strategies and changes in the supply chain implementing sustainable approaches and leveraging advanced technologies such as AI (Jones, 2023; Kumar et al., 2020; Schleper et al., 2021; Shen et al., 2021). Furthermore, based on a study by Kazancoglu et al. (Kazancoglu et al., 2022), flexibility, agility and responsiveness, towards resilience in the face of disruptions, are interdependent. Supply chain flexibility affect supply chain agility, while both of them directly affect supply chain responsiveness, therefore it is crucial for enterprises to adopt strategies that enhance these concepts. Additionally, according to Wang et al. (Wang et al., 2025), digitalization enhances supply chain resilience in the manufacturing sector improving the firms capability to address changes.

4.2.9 Increasing supply chain complexity due to globalization

The globalization of the market is leading to an intense competition, which in turn results in an increased complexity of the supply chains. In order for the companies to ensure competitive advantage, a quick response to disruptive events as well as the advent of Industry 4.0, they have adopted practices (e.g. multi-sourcing) to enable last minutes adaptations. This supplements the already complex network of businesses, making difficult for the supply chain management to ensure the efficient coopeation of the different flows (product, information) along the supply chain (Serdarasan, 2013). Especially, transitioning from local supply chains to global ones, presents an additional number of stakeholders and interactions among them. By extending their operations across borders they expose their

⁵ https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en

processes and procedures to new risks that can disrupt the flow of goods and information, therefore setting the development of new resources and capabilities such as strategic partnerships and advanced technologies essential. Emerging technologies such as AI, Blockchain and Analytics can transform the supply chain management facilitating visibility and traceability, while ensuring real-time responsiveness (Jones, 2023). As Brun et al. (Brun et al., 2020b) mentions, the adoption of technologies for traceability, the efficient collaboration and communication of the stakeholders, and the strong engagement of the different actors are crucial factors to address the increasing complexity of the supply chain facilitating an integrated and collaborative model.

4.2.10 Growing importance of data-driven decision-making

The complexity and the extent of the supply chain due to globalization, consumer behavior and disruptions, have led to the production of high amounts of data. Furthermore, the dynamic state of the supply chain environment forces organization to transform their traditional decision-making approaches and increasingly rely on advanced decision techniques. The data availability and the need for better supply chain insights have resulted on the growing importance of the data-driven decision-making for an effective supply chain management, to facilitate the improvement of operational efficiency and to upgrade the whole process. The manufacturing domain is actively seeking ways to exploit the unused data through implementing big data analytics and artificial intelligence (Awan et al., 2021). By leveraging data analytics, companies can make more informed, timely, and accurate decisions, leading to improved supply chain performance and competitive advantage (Maheshwari et al., 2021; Shashwat Agrawal et al., 2023). Based on the study of Redzeb (Redzeb, 2024), artificial intelligence improves supply chain management by automating tasks and making real-time decisions, while positively affects and promotes sustainability.

4.2.11 Need for better demand forecasting, inventory optimization and process automation

In the fast-paced and highly competitive environment, unexpected events, the volatile consumer behavior, the market dynamics and the high competitiveness in the market demand for constant changes in the supply chain. Companies that fail to upgrade their supply chain operations, are outperformed. Nowadays, firms are called to effectively manage their network to achieve quality, efficiency and cost-effectiveness, leading to integrating activities focusing on better predicting demand, optimizing inventory and automating processes (Albayrak Ünal et al., 2023; Tsintotas et al., 2025). Technologies such as advanced analytics provide valuable insights on consumer, while robotics enhance automation, streamlining repetitive tasks and reducing human-error. By aligning supply chain performance metrics with broader objectives and embracing a culture of continuous improvement, businesses can gain a decisive edge and ensure long-term sustainability.

4.3 Key drivers survey results

Section 4.3 presents the results from the analysis conducted based on the De Matel technique and the information collected from the key drivers survey.

The survey was completed by 10 different supply chain stakeholders, of which 6 were manufacturers, 2 were distributors, 1 was a technology provider and 1 was in the field of procurement, engineering and construction.

Company type

10 απαντήσεις

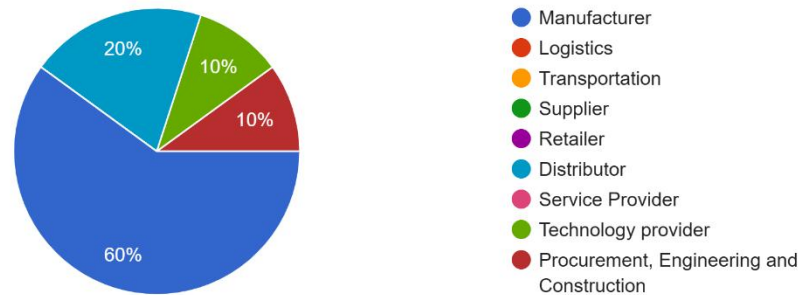


Figure 8: The supply chain stakeholder categorization.

In order to implement the DEMATEL technique, we have aggregated the answers from all the stakeholders. Each of the stakeholder had evaluated the direct influence between the factors, resulting in 10 individual relation-matrices. We have computed the arithmetic mean across all matrices to obtain a collective relation matrix.

Table 4: Direct Relation Matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	3	2.7	2.8	3.3	2.3	2.5	2.4	2.6	3.3
F2	3.3	0	2.8	2.8	2.3	2.1	2.5	2.2	2.4	3.4
F3	2.5	2.4	0	2.6	2.4	2.6	2.5	2.3	2	2.7
F4	2.9	2.5	2.9	0	3.1	2.8	2.9	2.5	2.5	2.9
F5	3.3	1.9	2.3	3	0	2.4	2.6	2.5	2.8	2.6
F6	2.9	1.9	2.5	2.4	2.4	0	2.6	2.2	2.6	2.3
F7	3	2.2	2.8	2.6	2.6	2.2	0	2.4	2.8	2.9
F8	2.9	2.6	2.5	2.8	2.8	2.5	2.4	0	2.7	2.9
F9	2.9	2.6	2.8	2.6	2.5	2.4	2.7	2.3	0	2.9
F10	3.4	2.9	2.9	2.7	2.4	2	2.7	2.8	2.9	0

Next step is finding the maximum row sum in order to normalize the direct relation matrix.

- F1 row sum = 24.9
- F2 row sum = 23.8
- F3 row sum = 22
- F4 row sum = 25 (largest value)
- F5 row sum = 23.4
- F6 row sum = 21.8
- F7 row sum = 23.5
- F8 row sum = 24.1
- F9 row sum = 23.7
- F10 row sum = 24.7

The normalized matrix (each cell value divided by 25) is presented below:

Table 5: The normalized matrix (N).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.000	0.120	0.108	0.112	0.132	0.092	0.100	0.096	0.104	0.132
F2	0.132	0.000	0.112	0.112	0.092	0.084	0.100	0.088	0.096	0.136
F3	0.100	0.096	0.000	0.104	0.096	0.104	0.100	0.092	0.080	0.108
F4	0.116	0.100	0.116	0.000	0.124	0.112	0.116	0.100	0.100	0.116
F5	0.132	0.076	0.092	0.120	0.000	0.096	0.104	0.100	0.112	0.104
F6	0.116	0.076	0.100	0.096	0.096	0.000	0.104	0.088	0.104	0.092
F7	0.120	0.088	0.112	0.104	0.104	0.088	0.000	0.096	0.112	0.116
F8	0.116	0.104	0.100	0.112	0.112	0.100	0.096	0.000	0.108	0.116
F9	0.116	0.104	0.112	0.104	0.100	0.096	0.108	0.092	0.000	0.116
F10	0.136	0.116	0.116	0.108	0.096	0.080	0.108	0.112	0.116	0.000

In order to derive the Total Influence Matrix, we will use the equation $T = N * (I - N)^{-1}$, where N is the normalized matrix and I is the identity matrix.

Table 6: The I-N matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1.00	-0.12	-0.11	-0.11	-0.13	-0.09	-0.10	-0.10	-0.10	-0.13
F2	-0.13	1.00	-0.11	-0.11	-0.09	-0.08	-0.10	-0.09	-0.10	-0.14
F3	-0.10	-0.10	1.00	-0.10	-0.10	-0.10	-0.10	-0.09	-0.08	-0.11
F4	-0.12	-0.10	-0.12	1.00	-0.12	-0.11	-0.12	-0.10	-0.10	-0.12
F5	-0.13	-0.08	-0.09	-0.12	1.00	-0.10	-0.10	-0.10	-0.11	-0.10
F6	-0.12	-0.08	-0.10	-0.10	-0.10	1.00	-0.10	-0.09	-0.10	-0.09
F7	-0.12	-0.09	-0.11	-0.10	-0.10	-0.09	1.00	-0.10	-0.11	-0.12
F8	-0.12	-0.10	-0.10	-0.11	-0.11	-0.10	-0.10	1.00	-0.11	-0.12
F9	-0.12	-0.10	-0.11	-0.10	-0.10	-0.10	-0.11	-0.09	1.00	-0.12
F10	-0.14	-0.12	-0.12	-0.11	-0.10	-0.08	-0.11	-0.11	-0.12	1.00

Following, we have to define the inverse (I-N) matrix, $(I - N)^{-1}$. Therefore, we have used the *minverse* function in excel.

Table 7: The Inverse I-N matrix, $(I - N)^{-1}$.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	3.10	1.85	1.99	2.00	1.99	1.77	1.93	1.80	1.92	2.13
F2	2.13	2.68	1.92	1.93	1.88	1.70	1.86	1.73	1.85	2.06
F3	1.96	1.65	2.69	1.79	1.76	1.60	1.73	1.61	1.71	1.90
F4	2.20	1.84	2.00	2.90	1.98	1.79	1.94	1.80	1.92	2.12
F5	2.10	1.72	1.88	1.91	2.77	1.68	1.83	1.71	1.83	2.00
F6	1.96	1.62	1.77	1.77	1.74	2.49	1.72	1.60	1.71	1.87
F7	2.10	1.74	1.90	1.90	1.87	1.68	2.74	1.71	1.84	2.02
F8	2.14	1.79	1.93	1.95	1.92	1.73	1.87	2.66	1.87	2.06
F9	2.11	1.76	1.91	1.91	1.88	1.70	1.85	1.72	2.75	2.03
F10	2.20	1.84	1.99	1.99	1.95	1.75	1.92	1.80	1.92	3.00

The total relation matrix is, $T = N * (I - N)^{-1}$:

Table 8: The Total Relation Matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0,00	0,22	0,22	0,22	0,26	0,16	0,19	0,17	0,20	0,28
F2	0,28	0,00	0,22	0,22	0,17	0,14	0,19	0,15	0,18	0,28
F3	0,20	0,16	0,00	0,19	0,17	0,17	0,17	0,15	0,14	0,20
F4	0,26	0,18	0,23	0,00	0,25	0,20	0,23	0,18	0,19	0,25
F5	0,28	0,13	0,17	0,23	0,00	0,16	0,19	0,17	0,21	0,21
F6	0,23	0,12	0,18	0,17	0,17	0,00	0,18	0,14	0,18	0,17
F7	0,25	0,15	0,21	0,20	0,19	0,15	0,00	0,16	0,21	0,23
F8	0,25	0,19	0,19	0,22	0,21	0,17	0,18	0,00	0,20	0,24
F9	0,24	0,18	0,21	0,20	0,19	0,16	0,20	0,16	0,00	0,24
F10	0,30	0,21	0,23	0,21	0,19	0,14	0,21	0,20	0,22	0,00

The sum along each row, indicates the direct or indirect effect of factor *i* on the other factors, while the sum along each column indicates the direct and indirect effects the factor *i* has received from the other factors.

Table 9: Sum values.

	R (sum along row)	C (sum along column)	R+C	R-C	Cause/effect
F1	1.93	2.28	4.21	-0.35	Effect
F2	1.82	1.55	3.37	0.27	Cause
F3	1.54	1.86	3.40	-0.32	Effect
F4	1.96	1.85	3.81	0.11	Cause
F5	1.75	1.8	3.55	-0.05	Effect
F6	1.53	1.46	2.99	0.07	Cause
F7	1.76	1.73	3.49	0.03	Cause
F8	1.85	1.49	3.34	0.36	Cause
F9	1.78	1.72	3.50	0.06	Cause
F10	1.92	2.1	4.02	-0.18	Effect

From Table 9, we can interpret based on the sum pairs R+C that *F1: Demand for improved efficiency, cost and waste reduction*, *F10: Need for better demand forecasting, inventory optimization and process automation* and *F4: Innovation potential and digital capabilities* are the factors that are highly involved on why companies aim in enhancing their resilience. They consist the primary reasons for the firms to take actions towards new resilient practices and technologies for improving the supply chain performance. These factors influence firms the most, since small changes in them or to them can affect the supply chain. They are considered prominent factors.

F8: Increasing supply chain complexity due to globalization influences the rest of the factors the most, while *F7: Enhanced supply chain resilience (risk management) and agility (flexibility)* has the least influence on the rest of the factors. Furthermore, *F1: Demand for improved efficiency, cost and waste reduction* is the most heavily affected factor in case of changes in the other factors, while *F5: Supply Chain Sustainability and Environment* is the least influenced.

By evaluating the R-C pairs, we have categorized the factors to either Causes or Effects. A factor is a Cause ($R-C > 0$) when it influences other factors more than it is influenced, while the vice versa, if the factor is an Effect ($R-C < 0$). We have identified six factors as Cause (*F2: Customer expectations, F4: Innovation potential and digital capabilities, F6: Regulatory requirements for traceability and compliance, F7: Enhanced supply chain resilience (risk management) and agility (flexibility), F8: Increasing supply chain complexity due to globalization, F9: Growing importance of data-driven decision-making*) which should be considered drivers, since changes in these areas can propagate through the supply chain. Four factors have been categorized as Effects (*F1: Demand for improved efficiency, cost and waste reduction, F3: Need for real-time visibility and transparency, F5: Supply Chain Sustainability and Environment, F10: Need for better demand forecasting, inventory optimization and process automation*) which are influenced primarily by others and their implementation mostly affects the supply chain dynamics, but they aren't considered drivers.

4.4 Strategic Importance

Nowadays, companies are striving to stay ahead of the competition investing in new technologies and innovation practices. Supply Chain Management is the strategic coordination of the flow of goods and any information along the supply chain, from sourcing to producing and delivering the final product. The focus of the supply chain management is to ensure that each operational step across the network is efficiently working aiming in cost optimization, quality and customer satisfaction. Therefore, the modern supply chain is heavily dependent on advanced tools to facilitate visibility, responsiveness and efficiency along the whole chain as well as requires close collaboration both internally and externally (Blanchard, 2021). To achieve this, enterprises implement different technologies (Figure 9). These technologies ensure the well-managed network enhancing its strategic value towards competitiveness.

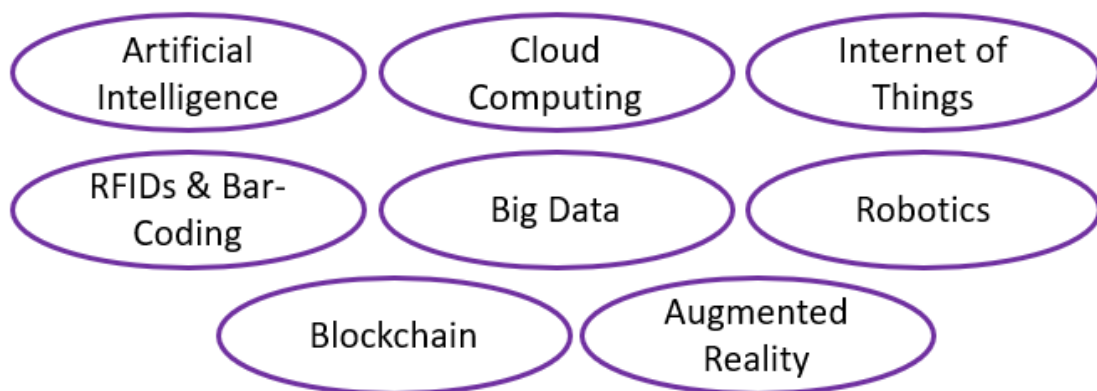


Figure 9: State-of-the art technologies in the supply chain.

The integration of these emerging technologies has reshaped supply chain management by enhancing efficiency, reducing costs, and creating more sustainable operations. Among these technologies, artificial intelligence (AI) plays a leading role. Big Data and AI's ability to process vast amounts of data and predict trends has revolutionized the traditional supply chain by providing insights to businesses for improved risk management, demand forecasting and operation optimization. Moreover, cloud computing facilitates information sharing across all the stakeholders in real-time and facilitates collaboration, while Internet of Things enables real-time monitoring and data updates for smart decision-making. The

barcoding technology assists in tracking the goods constantly to ensure efficient inventory management and robotics drive the automation aspect, while augmented reality overlays the physical information to a digital world. These are accompanied by blockchain to secure all the information exchange facilitating and enhancing transparency and visibility. Furthermore, it is important to mention the sustainable aspect integration. Supply chains are increasingly oriented towards the implementation of sustainable practices. This entails reducing the environmental footprint of operations through new technology integration and innovation practices. Based on the information from section 2, we have compiled Table 9 which present the technology and the strategic impact it has on supply chain operations.

Table 10: Technology and its strategic impact.

Technology	Impact area
Artificial Intelligence	<ul style="list-style-type: none"> - Processes and analyzes data to forecast demand trends and optimize material sourcing. - Improves supplier selection, logistics, and overall operational efficiency by enabling proactive decision-making.
Cloud computing	<ul style="list-style-type: none"> - Centralizes data and applications, enabling access from anywhere. - Enhances real-time information exchange and collaboration among stakeholders. - Improves efficiency, agility, transparency, customer service, and sustainability through streamlined processes and cost reduction.
Internet of Things	<ul style="list-style-type: none"> - Connects devices and sensors to provide real-time monitoring across the supply chain. - Enhances interconnectivity, intelligence, and visibility. - Supports integration with other technologies (e.g., RFID, middleware) to improve flexibility, efficiency, and to deliver social, economic, and environmental benefits.
RFIDs & Bar-coding	<ul style="list-style-type: none"> - Enables wireless identification, tracking, and monitoring of products. - Improves process efficiency and accuracy in transportation and inventory management. - Enhances transparency and traceability when used individually or alongside IoT systems.
Big Data	<ul style="list-style-type: none"> - Collects and analyzes large volumes of structured/ unstructured data. - Facilitates faster decision-making, risk management, and new product development. - Enhances supplier management and supports the design of robust, sustainable supply chains through actionable insights.
Robotics	<ul style="list-style-type: none"> - Automates repetitive and labor-intensive tasks in warehousing and production. - Improves efficiency, accuracy, and safety while reducing operational costs. - Includes innovations such as autonomous robots, drones, and collaborative systems that adapt to changes in real time.
Blockchain	<ul style="list-style-type: none"> - Offers a decentralized, secure, and transparent ledger for recording transactions. - Enhances traceability and data interoperability across complex, global supply chains.

	- Supports the creation of an integrated ecosystem that improves security and efficiency among various stakeholders.
Augmented reality	<ul style="list-style-type: none"> - Overlays digital information onto the physical world for improved operational accuracy. - Speeds up order fulfillment and reduces warehouse errors through real-time visual guidance. - Enhances inventory management, equipment maintenance, training, and overall productivity despite initial integration challenges and costs.

Moreover, based on the DEMATEL Technique implemented in the Key drivers section, we have identified 6 main drivers (Cause) for supply chain changes, which are placed below, because on their positive R-C score (which means that influence mainly the other factors). The further a bar is from zero, the stronger the cause or effect role of the factor. The drivers are the key factors which the companies need to provide strategic importance since small changes in them will propagate changes in the supply chain. The first four causes are the main strategic points to be included in a companies changing plan, while the remaining two, although important, are secondary drivers.

- F8: Increasing Supply Chain Complexity Due to Globalization
 - Central driver for change
- F4: Innovation Potential and Digital Capabilities
 - Most involved driver in the system, key enabler transformation
- F2: Customer Expectations
 - High leverage point for change, customer pressure is a pressure point for companies
- F9: Growing Importance of Data-Driven Decision-Making
 - Decision making for optimal next steps
- F7: Enhanced Supply Chain Resilience (Risk Management) and Agility (Flexibility)
- F6: Regulatory Requirements for Traceability and Compliance

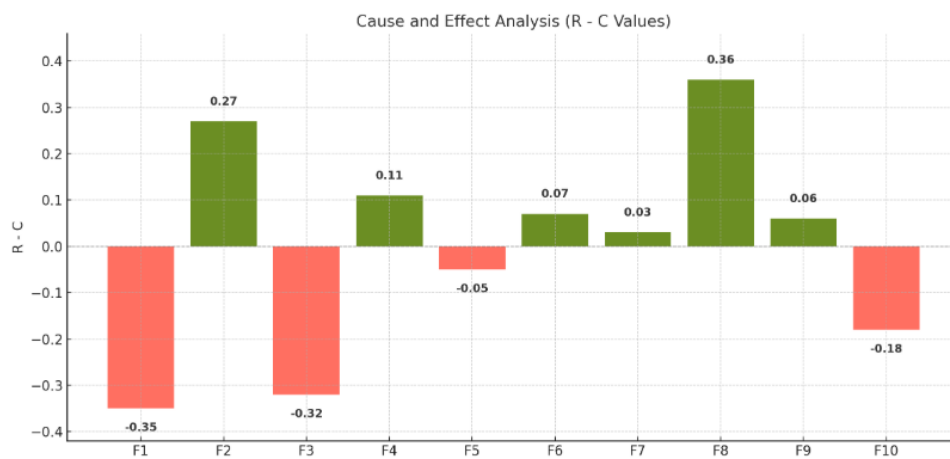
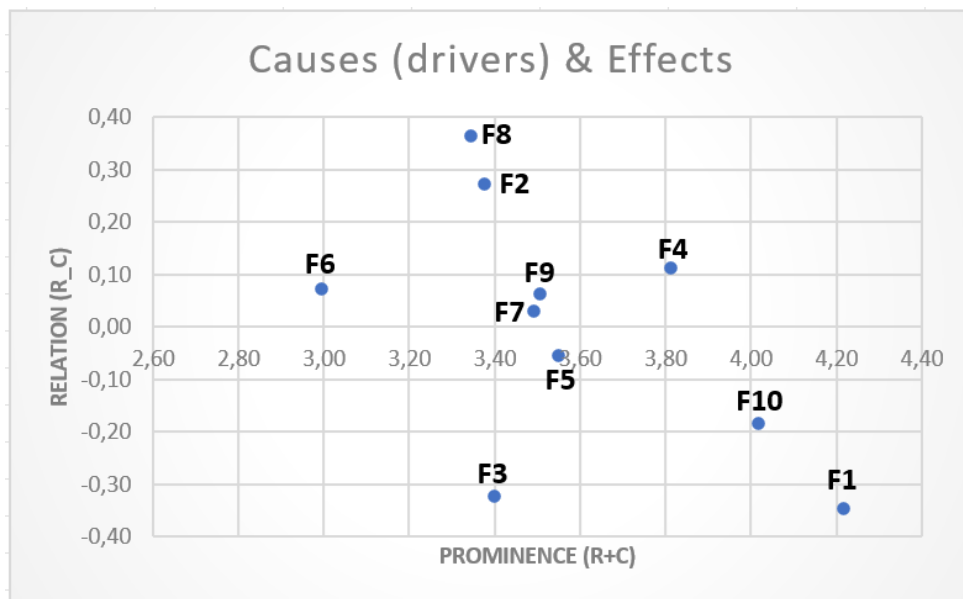


Figure 10: Causes and Effects.

However, the effect factors are equally important. They affect supply chain dynamics, although they don't bring great changes to the supply chain (in case of a change in them). However, they should be monitored as Key Performance Indicators.

5 Case Study

5.1 Case study presentation

The aim of the single case study survey was to complete an in-depth analysis of the supply chain digitalization of a company. To achieve this, a questionnaire was developed which was separated in three different time periods.

- 10 years prior supply chain digitalization level
- Present supply chain digitalization level
- Future supply chain digitalization level

The questions of each time period included are presented below.

10 years prior supply chain digitalization level

- How would you describe the state of your supply chain operations 5-10 years ago? (e.g., manual, semi-automated, fully automated)
- What key technologies or systems were used in your supply chain during this period? (e.g., ERP systems, spreadsheets, manual processes)?
- Did your company implement any software solutions for inventory management, order processing or logistics at that time?
- How were communication and data exchange between different departments and suppliers managed?
- Did you use any data analytics or forecasting tools to predict demand or optimize supply chain processes?
- What were the main challenges or limitations in the supply chain due to lack or limited use of digital tools?
- Were there any major supply chain disruptions during this period? If yes, how were they handled?

Present supply chain digitalization level

- How would you rate now the efficiency of your supply chain processes from 1 (lowest) to 5 (highest)?
- What key technologies, systems or digital tools are currently being used in your supply chain?
- Have you increased the automation level of your processes? Are there any automated systems in place for production, inventory management or logistics?
- Are you using any state-of-the-art technology such as Artificial Intelligence, Blockchain, IoT, cloud computing? In which way?
- Do you use data analytics for decision making in the supply chain?
- How is data collected, processed and shared across the supply chain today?
- How has the digitalization of your supply chain improved efficiency, speed or accuracy?
- How do you communicate and collaborate with suppliers, distributors, and other partners in the supply chain today? (e.g., digital platforms, real-time communication tools)
- Do you have any platforms for real-time monitoring or tracking of shipments, inventory levels, or production progress?

- Are there any areas where data-driven insights have led to significant improvements or cost savings?
- What were/are the key drivers to increase the digitalization of your supply chain?
- Despite digital advancements, what challenges still exist in your supply chain today? (e.g., data silos, integration issues, cybersecurity concerns)
- How have these challenges impacted your supply chain efficiency and cost?
- Have you thought of implementing best practices such remanufacturing/reuse/....?

Future supply chain digitalization level

- Do you have a plan (e.g. 5-year period) to further optimize supply chain processes?
- What are your key digitalization goals for your supply chain over the next 3-5 years?
- Are there any specific technologies you plan to implement or expand upon in the near future (e.g., AI, automation, blockchain, IoT, cloud-based solutions)?
- What kind of investments is the company planning to make in digital supply chain tools and technologies?
- How do you prioritize which areas of your supply chain to digitalize next? (e.g., procurement, logistics, forecasting)
- Are there plans to further automate supply chain operations? If so, which specific areas will benefit from automation or AI implementation?
- How do you foresee AI transforming decision-making, logistics, and inventory management in your supply chain?
- What role will data and analytics play in your future supply chain strategy? Are you looking to implement more advanced data tools, such as predictive analytics, machine learning, or big data solutions?
- How do you plan to leverage real-time data and predictive insights to enhance supply chain performance?
- Are there any new strategies to mitigate risks, ensure resilience, or deal with disruptions in the digital supply chain?
- Are you exploring new models of supply chain collaboration, such as blockchain for transparency or digital platforms for partner engagement?
- How do you see digital tools contributing to a more sustainable supply chain in the future?

5.1.1 10 years prior supply chain digitalization level

Ten years ago, the company’s supply chain operations were predominantly reliant on manual processes, reflecting limited digital integration and a lack of advanced technological support. Communication with suppliers and clients was largely conducted via phone calls and emails, which frequently led to delays in decision-making, particularly when coordinating with external partners. While the overall supply chain could be categorized as largely manual, certain processes—specifically in the production stage—demonstrated elements of semi-automation. A small proportion of production lines were partially automated through the use of robotic arms, enabling some level of efficiency. However, the core product handling, including the movement of products from one module to another, remained entirely manual.

In terms of technological adoption, the company utilized Enterprise Resource Planning (ERP) systems to manage inventory, acting as an in-house communication link between the

warehouse and production departments. Despite this integration, data recording and analysis outside of the ERP system heavily relied on Excel spreadsheets, creating inefficiencies in critical areas:

- **Inventory Tracking:** Employees relied on Excel for record-keeping and ad-hoc analyses, which lacked the real-time accuracy and automation required for streamlined inventory management.
- **Production Data Management:** Production activities were tracked partially through spreadsheets and partially within the ERP system. This dual approach not only created redundancies but also increased the risk of errors and data inconsistencies.

The company’s communication and collaboration with suppliers and clients were performed manually, limiting overall transparency across the supply chain. The lack of real-time data sharing or updates created significant operational challenges, including delays in placing and receiving orders as well as in fulfilling customer demands. These inefficiencies were further exacerbated by limited visibility into inventory levels due to inadequate digital tracking systems. This, in turn, resulted in difficulties maintaining accurate stock levels, leading to frequent stockouts and subsequent disruptions in production and delivery.

The absence of data-driven insights compounded these challenges. Without advanced analytics or forecasting tools, inventory planning and demand forecasting were dependent on historical data and human judgment. This reliance introduced inaccuracies and inefficiencies, which often led to suboptimal scheduling, prolonged lead times, and increased transportation costs. These shortcomings adversely affected customer satisfaction and prevented the supply chain from achieving optimal performance.

5.1.2 Present supply chain digitalization level

Addressing the present digitalization level of the supply chain, the company assessed as 3 in a scale from 1(lowest) to 5 (highest). This proves that although efforts have been made to address the limitations and inefficiencies identified, exhibiting improvements in automation, real-time visibility and communication, further enhancements are needed.

Still the ERP system remains as the core system in the company’s digital infrastructure, managing production, warehousing, invoices and supporting the supply chain operations. Additionally, a Warehouse Management System (WMS) was introduced in the processes to provide real-time visibility of warehouse stock levels and to automate inventory related tasks. It can integrate with the ERP system, streamlining data flow between production and inventory management. Furthermore, the digital tools arsenal has broaden by implementing Barcodes and Scanners, exploiting cloud computing technologies for real time inventory tracking, using Batch Numbering and the Zoho Platform.

- **Barcodes and Scanners:** By scanning products, the company automates updates to inventory and production data in the ERP, minimizing manual entry.
- **Cloud Computing:** Used for real-time inventory checking and data storage, enhancing accessibility and collaboration among staff.
- **Zoho Platform:** Facilitates both internal and external communication, improving coordination across departments and with suppliers.
- **Batch Numbering:** Implemented to trace back any flawed products to their production batches, enabling swift corrective actions and improved quality control.

In parallel, robotic arms are now more widespread on production lines, reducing manual intervention and increasing throughput. Manual product transfers from one module to another have decreased substantially, further enhancing efficiency and consistency in quality.

Many methods and channels from the previous period still remains, for example material ordering through mails and sharing information across supply chain, however it is crucial to mention that some suppliers have introduced portals where the company can monitor order and invoices. Also, there was an update such as the improved use of the ERP and WMS systems for data collection (inventory, production schedules, procurement and financial transactions) or the cloud platform for internal sharing. Nonetheless, although the company technologically progressed, decision-making and/or forecasting are relying on spreadsheets.

By upgrading their processes, the company managed better and optimized their inventory minimizing unnecessary raw material reducing also warehouse costs. The real-time stock visibility and barcode scanning have decreased stockouts and improved warehouse turnover, while automation of repetitive tasks and integration of systems have sped up processing times and reduced manual errors. One of the concerns is Cybersecurity, since digital adoption has increased, management has become more aware of cybersecurity risks. Thus far, however, no significant disruptions or cost impacts from cyber threats have been reported.

Lastly, important to mention is the implementation of circular economy practices. The company has begun to systematically implement reuse, remanufacturing, and recycling. Although these processes still rely on manual decisions by employees, they form a solid base for a more sustainable and resilient supply chain.

5.1.3 Future supply chain digitalization level (5 years)

The company plans to build on the existing digital infrastructure to a more interconnected, optimized and resilient supply chain. Driven by a number of factors such as: Business evolution and transformation, customer expectation, innovation potential, following ESG factors, inventory optimization and resilience, the company is focused on investing in technologies in the next five years.

The company intends to implement a customer-oriented system where orders can be placed online, providing real-time visibility of the product inventory (order management system). The client will be able to receive instant feedback on estimated delivery dates, as well as track placed orders receiving updates about their status. Such a system will enhance communication with clients and provide valuable data for scheduling transportation and production processes. Still, the main goals remaining the production and inventory optimization. The primary objective is to fully automate the production lines, adopting more robotic arms to minimize human intervention and reduce errors. Also, the plan includes integrating production data into the cloud platform allowing real-time visibility into Key Performance Indicators (KPIs) and production metrics across the organization. In order to support the above steps, the company participates in Greek-funded projects mainly in production and maintenance. Procurement and logistics will receive priority for the next phase of digitalization—particularly to optimize lead times and adapt swiftly to market or

geopolitical disruptions. The type of products (on demand) provides some freedom in inventory levels, since a slight overstocking is not a problem. However, inventory and production optimization to address the demand is still crucial for the efficient operation of the factory. Forecast is needed internally to maintain the necessary stock to the right amount.

Although advanced forecasting tools such as predictive analytics or machine learning are not immediately planned, the company recognizes their potential in maintaining adequate inventory levels and mitigating disruptions. The experience of rising raw material costs during the Ukraine war highlighted the importance of real-time data and agile decision-making.

Furthermore, the appropriate attention is given to sustainability and risk mitigation. Focusing on the optimal implementation of best practices such as remanufacturing, reuse and recycle are essential in ensuring supply chain resilience and environmental responsibility. In this, the possible implementation of supplier engagement platforms could support the streamlining of procurement processes, reducing lead times and enhancing collaboration.

5.1.4 The Digitalization pathway of the company

Summarizing the information from the previous sub-sections, the below figure presents the implemented technologies in the timeline. The key milestones in each time period are the initial adoption of the ERP, which established the foundation for managing the inventory and the production, the implementation of WMS system and the cloud computing offering real-time visibility and some degree of automation and lastly the order managing system that will offer to customers direct interaction and real-time updates, driving data-informed planning and logistics.

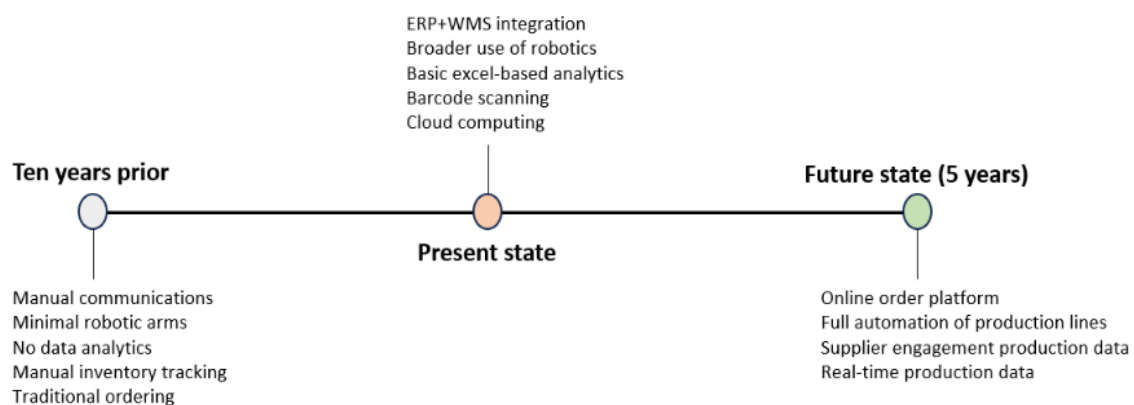


Figure 11: The technology timeline of the company.

Keeping the different timeframes, 10 years prior, the supply chain incorporated limited digitalization, mainly manual processes and absence of digital tools, lacking real-time visibility, seamless collaboration and transparency, and communication with the suppliers or clients. At present, progress has been made by the integration of technologies increasing the automation level and enabling real-time inventory visibility. Also, batch numbering supports the traceability aspect. In the next five years, the objective is to fully automate the

production lines and ensure a seamless collaboration and communication with the customers or suppliers, as well as address further the sustainability aspect and the customer experience.

Table 11: Technologies and skills per timeframe.

Time Period	Technologies	Skills
10 years prior	ERP system, robotic arms	<ul style="list-style-type: none"> - Basic inventory management - Semi-automated production
Present State	ERP-WMS integration, barcoding, cloud computing	<ul style="list-style-type: none"> - Real-time inventory visibility - Enhanced traceability - Streamlined internal communication - Improved data accuracy
Next 5 years	Full automation of production, Order management system	<ul style="list-style-type: none"> - Seamless supplier collaboration - Circular economy optimization - Enhanced customer satisfaction

Table 12: The evolution of the supply chain in the different time periods.

Supply Chain Digitalization aspect	10 years prior	Present State	Next 5 years
Automation level	Semi-automated production (limited robotic arms)	Increased automation in production and inventory	Fully automated production lines, automated circular economy practices
Data Management	Manual data entry, Excel for tracking	Real-time inventory tracking via WMS, cloud	Integrated real-time production and inventory data
Communication/ Collaboration	Manual communication (email, phone calls)	Zoho platform for internal communication	Digital supplier engagement platforms, online order management for real-time customer interaction
Traceability	Minimal traceability, no batch tracking	Batch numbering for quality assurance	Digital supplier engagement platforms
Visibility	Mainly manual tracking of inventory	Real-time visibility with WMS and cloud	Order management system

Innovation practices	Largely manual decisions on reuse/recycling	Largely manual decisions on reuse/recycling	Largely manual decisions on reuse/recycling
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Resilience Roadmap

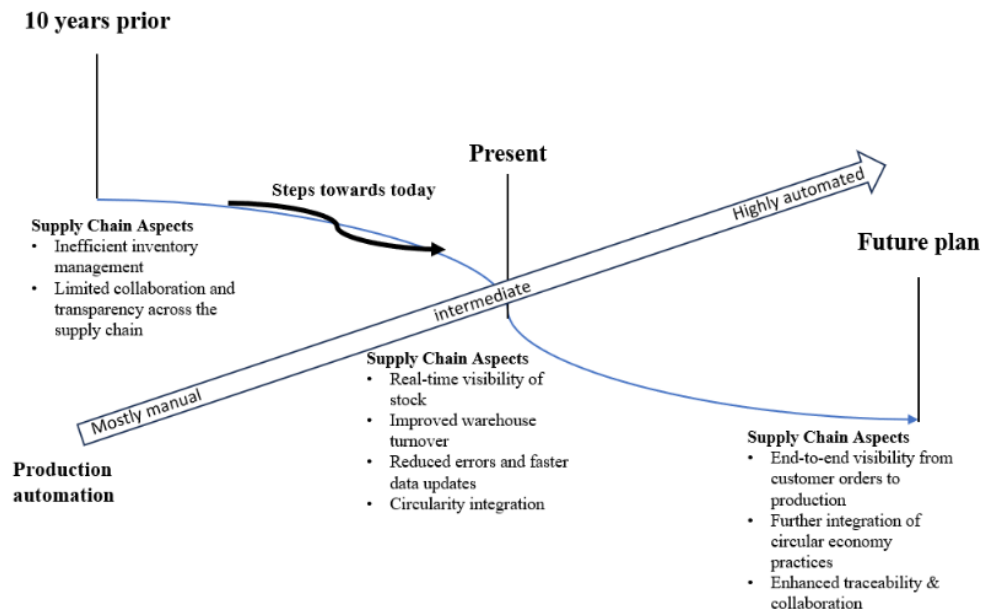


Figure 12: The Resilience Roadmap.

5.2 Strategic Importance aspect in the case study

The implementation of the Enterprise Resource Planning System (ERP) supports the processes across the organization enhancing decision-making and information exchange. It facilitates data exchange between stakeholders combined with cloud computing enabling access from anywhere and assisting real-time collaboration. The integration with the WMS further enhances this direction. Furthermore, the company is leveraging cloud computing for real-time inventory tracking and enhanced visibility. The implementation of robotic arms focuses on automating tasks to enhance efficiency, accuracy and safety indicating a strong commitment to operational efficiency. The implementation of bar coding enhances traceability, improving inventory management and relative processes. Nonetheless, as it is illustrated in Table 13, the case study company is still in the early stages of its digitalization journey, implementing a small number of technologies outlined. Based on the strategic aspect developed in S4.4, we compare the present state of the case study with the technologies mentioned in Table 10.

Table 13: Comparison of technologies and their impacts with the case study.

Technology	Impact area	Case study comparison
Artificial Intelligence	Processes and analyzes data to forecast demand trends and optimize material sourcing.	No

	Improves supplier selection, logistics, and overall operational efficiency by enabling proactive decision-making.	No
Cloud computing	Centralizes data and applications, enabling access from anywhere.	Yes
	Enhances real-time information exchange and collaboration among stakeholders.	Yes
	Improves efficiency, agility, transparency, customer service, and sustainability through streamlined processes and cost reduction.	Yes
Internet of Things	Connects devices and sensors to provide real-time monitoring across the supply chain.	No
	Enhances interconnectivity, intelligence, and visibility.	No
	Supports integration with other technologies (e.g., RFID, middleware) to improve flexibility, efficiency, and to deliver social, economic, and environmental benefits.	No
RFIDs & Bar-coding	Enables wireless identification, tracking, and monitoring of products.	Yes
	Improves process efficiency and accuracy in transportation and inventory management	Yes
	Enhances transparency and traceability when used individually or alongside IoT systems.	Yes
Big Data	Collects and analyzes large volumes of structured/unstructured data.	No
	Facilitates faster decision-making, risk management, and new product development	No
	Enhances supplier management and supports the design of robust, sustainable supply chains through actionable insights.	No
Robotics	Automates repetitive and labor-intensive tasks in warehousing and production.	Yes
	Improves efficiency, accuracy, and safety while reducing operational costs.	Yes
	Includes innovations such as autonomous robots, drones, and collaborative systems that adapt to changes in real time.	No
Blockchain	Offers a decentralized, secure, and transparent ledger for recording transactions	No
	Enhances traceability and data interoperability across complex, global supply chains	No
	Supports the creation of an integrated ecosystem that improves security and efficiency among various stakeholders.	No
Augmented reality	Overlays digital information onto the physical world for improved operational accuracy.	No
	Speeds up order fulfillment and reduces warehouse errors through real-time visual guidance.	No

	Enhances inventory management, equipment maintenance, training, and overall productivity despite initial integration challenges and costs.	No
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Furthermore, we have implemented the DEMATEL technique based on the questionnaire the case study company filled (Table 14).

Table 14: DEMATEL technique based on the case study questionnaire.

	R (sum along row)	C (sum along column)	R+C	R-C	Cause/effect
F1	0.21	0.91	1.12	-0.7	Effect
F2	0.14	0.19	0.33	-0.05	Effect
F3	0.26	0.57	0.83	-0.31	Effect
F4	0.2	0.49	0.69	-0.29	Effect
F5	0.22	0.35	0.57	-0.13	Effect
F6	0.15	0.35	0.5	-0.2	Effect
F7	0.22	0.44	0.66	-0.22	Effect
F8	0.39	0.27	0.66	0.12	Cause
F9	0.28	0.41	0.69	-0.13	Effect
F10	0.27	0.4	0.67	-0.13	Effect

We can see that there are changes on the Causes and Effects with the ones derived from the aggregated values in S4.3. Comparing with S4.3, there is only one driver (common - green color):

- F8: Increasing supply chain complexity due to globalization

This difference is understandable, since S4.3 took into consideration the aggregated opinion of the responded companies. Based on the DEMATEL technique, it is obvious that the company attaches importance to the demand for improved efficiency, cost and waste reduction. Moreover, as a key factor is also defined the factor F3: Need for real-time visibility and transparency, collaboration and communication across the supply chain, which can also be derived from the in-depth digitalization analysis completed in sub-sections S5.1.2 – S5.1.4. Categorizing the factors based on their “prominence” value, the main reasons companies are set to integrate the resilience aspect in the supply chain, the case study deems as most important (the first five):

- F1: Demand for improved efficiency, cost and waste reduction
- F3: Need for real-time visibility and transparency, collaboration and communication across the supply chain
- F4: Innovation potential and digital capabilities
- F9: Growing importance of data-driven decision-making
- F10: Need for better demand forecasting, inventory optimization and process automation

6 Results

6.1 Key Drivers

The DEMATEL analysis revealed that the main key driver for enhancing resilience in supply chain is the increased complexity due to globalization. The supply chain complexity consist of a challenge to organizations having to coordinate a number of stakeholders efficiently. This forces them to rethink and redesign their approaches in implementing innovation approaches and digital technologies. Additionally to this, the need for improved efficiency, cost-effectiveness and waste management as well as for efficient demand forecasting and inventory optimization are prominent factors.

Furthermore, the Cause factors such as customer expectation and innovation potential play a crucial role in driving the supply chain transformation. By investing in advanced digital solutions and fostering innovation companies set themselves towards creating a resilient, agile supply chain that is well-prepared to navigate the intense landscape of global operations. Targeting the key drivers the DEMATEL method resulted sets indirectly the way towards effecting the whole supply chain by improving efficiency and cost reduction, facilitating visibility and transparency, supporting sustainability and efficient waste management as well as better demand forecasting, essential blocks to acquire and maintain a competitive advantage.

6.2 Single use case

The plastic manufacturing company’s digital transformation illustrates a strategic move away from predominantly manual operations toward more integrated, automated, and data-driven processes. Over the last decade, the ERP system and incremental automation of production lines played a pivotal role in modernizing the supply chain. Today, the adoption of WMS, barcoding technology, and cloud computing continues to boost efficiency, accuracy, and real-time visibility. However, challenges such as cybersecurity, limited advanced analytics, and some remaining manual processes highlight the continuous need for improvement and strategic planning.

Looking ahead, the company’s aspirations to implement an online order management system, expand cloud-based monitoring, and potentially explore AI-driven applications underline its commitment to resilience, customer satisfaction, and sustainability. While the focus on predictive analytics and more advanced data science may be deferred in favor of immediate operational optimizations, the company remains open to adopting these tools as needs evolve.

The company’s digitalization pathway reflects a steady acquisition of smart supply chain benefits, transitioning from a largely manual supply chain to a partially automated one, and aiming for full digital integration in the future. While the company has made significant steps in improving efficiency, visibility, and traceability, it still lacks advanced predictive capabilities, seamless supplier integration, and fully automated sustainability practices. With its planned cloud expansion, and online order management, the company is well-positioned to achieve a resilient, sustainable, and customer-centric smart supply chain in the coming years.

7 Conclusion

In the dissertation “*“Leveraging Digital Technologies and Innovation Practices for Strategic Supply Chain Management to achieve resilience and sustainability”*”, the resilience and sustainability aspect of the supply chain was researched. Main points of the thesis were the description of state-of-the art technologies that support the digitalization of the supply chain as well as the two main surveys which were conducted.

The first survey’s primary objective was to derive and understand the key factors that lead to the supply chain digitalization with the aim to achieve a sustainable and resilience supply chain that boost the strategic perspective of the supply chain management. A literature review resulted in 10 key factors. A questionnaire was developed and shared to companies from which there were 10 responses. Based on the response, the DEMATEL technique was implemented and the “prominence” factors as well as the main factors were derived.

The second survey was focused on the in-depth analytics of the supply chain digitalization of a case study in the plastic sector. A questionnaire was developed and through an interview and the validation of the answers the digitalization pathway of the company was formed for three different time periods (10 years prior supply chain state, present supply chain state, future supply chain state).

Furthermore, the strategic importance of the key factors and the technologies was documented, according to information from sections S2 & S4 and was compared with the present state of the case study and the importance the company attaches to them.

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Appendix A: “Key Driving Factor survey”

Leveraging Digital Technologies and Innovation Practices for Strategic Supply Chain Management to achieve resilience and sustainability

* Υποδεικνύει απαιτούμενη ερώτηση



Key Driving Factors

Below, the Key Driving Factors, as they have been defined from the bibliography are presented

- F1: Demand for improved efficiency, cost and waste reduction
- F2: Customer expectations
- F3: Need for real-time visibility and transparency, collaboration and communication across the supply chain
- F4: Innovation potential and digital capabilities
- F5: Supply Chain Sustainability and Environment
- F6: Regulatory requirements for traceability and compliance
- F7: Enhanced supply chain resilience (risk management) and agility (flexibility)
- F8: Increasing supply chain complexity due to globalization
- F9: Growing importance of data-driven decision-making
- F10: Need for better demand forecasting, inventory optimization and process automation

Dear Madam/Sir

For the research needs of the Post Graduate thesis entitled “Leveraging Digital Technologies and Innovation Practices for Strategic Supply Chain Management to achieve resilience and sustainability”, we would like to invite you to participate in our survey. The elaboration of the Diploma Thesis is a basic prerequisite for the successful completion of the Master in Business Administration (M.B.A.) of the Hellenic Open University (H.O.U.).

The study is focused on the Key Driving Factors that lead the Supply Chain Digitalization, as they have been defined based on the study of a 199 article collection queried with the terms “Supply Chain”, “Digitalization”, “Manufacturing”. The aim of this questionnaire is to understand the relationships between the different factors and the influence they have on each other.

The collected data will be used for the research needs of this diploma thesis.

Thank you in advance for your cooperation.

All information is confidential and their use in the diploma thesis will be anonymous.

Company Name *

Η απάντησή σας _____

Company Place *

Η απάντησή σας _____

Company size (number of personnel) *

- ☐ <50
- ☐ between 50 and 200
- ☐ >200

Company type *

- ☐ Manufacturer
- ☐ Logistics
- ☐ Transportation
- ☐ Supplier
- ☐ Retailer
- ☐ Distributor
- ☐ Service Provider
- ☐ Technology provider
- ☐ Άλλο: _____

How does the F1 factor “Demand for improved efficiency, cost and waste reduction” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
- 1: Very low correlation/effect
- 2: Low correlation/effect
- 3: High correlation/effect
- 4: Very High correlation/effect

	0	1	2	3	4
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F2 factor “Customer expectations” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
- 1: Very low correlation/effect
- 2: Low correlation/effect
- 3: High correlation/effect
- 4: Very High correlation/effect

	0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

<p>How does the F3 factor <i>“Need for real-time visibility and transparency, collaboration and communication across the supply chain”</i> correlates/affects the rest of the factors. Please follow the rating scale:</p> <p>0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect</p>						<p>How does the F4 factor <i>“Innovation potential and digital capabilities”</i> correlates/affects the rest of the factors. Please follow the rating scale:</p> <p>0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect</p>					
	0	1	2	3	4		0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

<p>How does the F5 factor <i>“Supply Chain Sustainability and Environment”</i> correlates/affects the rest of the factors. Please follow the rating scale:</p> <p>0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect</p>						<p>How does the F6 factor <i>“Regulatory requirements for traceability and compliance”</i> correlates/affects the rest of the factors. Please follow the rating scale:</p> <p>0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect</p>					
	0	1	2	3	4		0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F7 factor “Enhanced supply chain resilience (risk management) and agility (flexibility)” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
1: Very low correlation/effect
2: Low correlation/effect
3: High correlation/effect
4: Very High correlation/effect

	0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F8 factor “Increasing supply chain complexity due to globalization” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
1: Very low correlation/effect
2: Low correlation/effect
3: High correlation/effect
4: Very High correlation/effect

	0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F9 factor “Growing importance of data-driven decision-making” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
1: Very low correlation/effect
2: Low correlation/effect
3: High correlation/effect
4: Very High correlation/effect

	0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for better demand forecasting, inventory optimization and process automation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F10 factor “Need for better demand forecasting, inventory optimization and process automation” correlates/affects the rest of the factors. Please follow the rating scale:

- 0: No correlation/effect
1: Very low correlation/effect
2: Low correlation/effect
3: High correlation/effect
4: Very High correlation/effect

	0	1	2	3	4
Demand for improved efficiency, cost and waste reduction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer expectations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Need for real-time visibility and transparency, collaboration and communication across the supply chain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Innovation potential and digital capabilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supply Chain Sustainability and Environment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Regulatory requirements for traceability and compliance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Enhanced supply chain resilience (risk management) and agility (flexibility)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increasing supply chain complexity due to globalization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growing importance of data-driven decision-making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How does the F1 factor "Demand for improved efficiency, cost and waste reduction" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

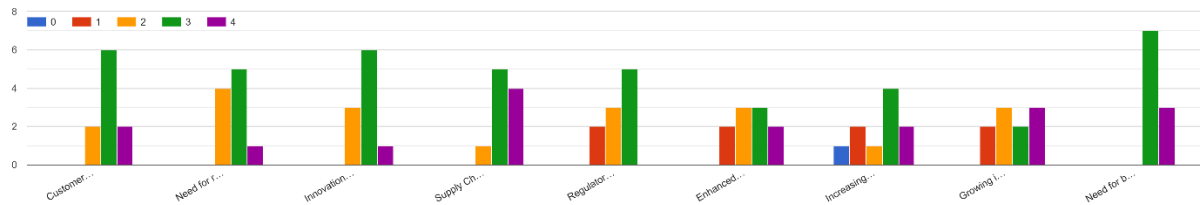


Figure 13: Influence of the “Demand for improved efficiency, cost and waste reduction” factor to the rest.

How does the F2 factor "Customer expectations" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

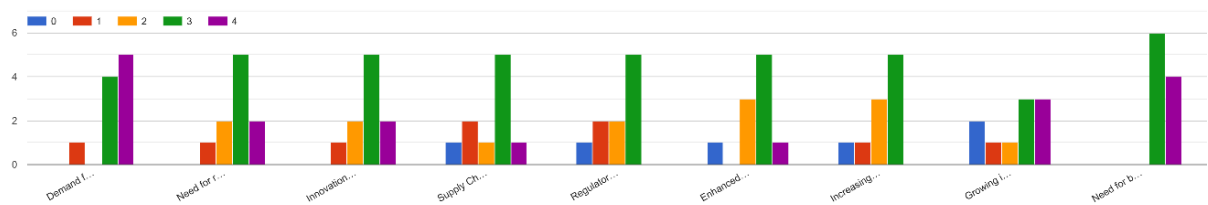


Figure 14: Influence of the “Customer expectations” factor to the rest.

How does the F3 factor "Need for real-time visibility and transparency, collaboration and communication across the supply chain" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

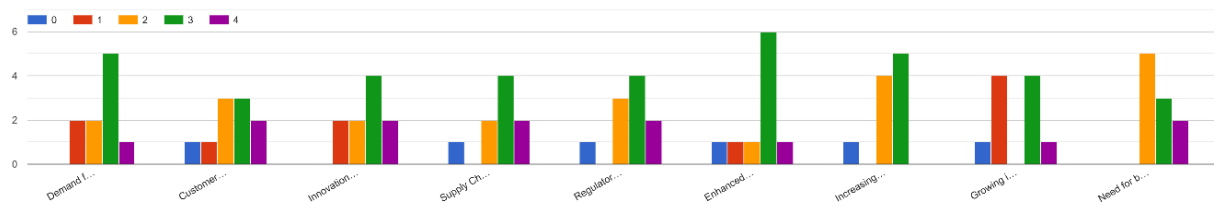


Figure 15: Influence of the “Need for real-time visibility and transparency, collaboration and communication across the supply chain” factor the the rest.

How does the F4 factor "Innovation potential and digital capabilities" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

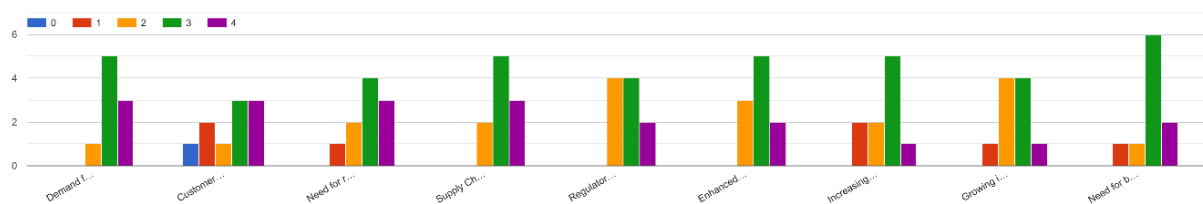


Figure 16: Influence of the “Innovation potential and digital capabilities” factor to the rest.

How does the F5 factor "Supply Chain Sustainability and Environment" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

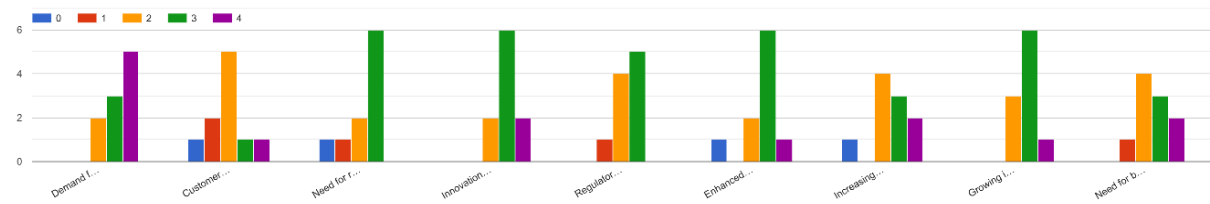


Figure 17: Influence of the “Supply Chain Sustainability and Environment” factor to the rest.

How does the F6 factor "Regulatory requirements for traceability and compliance" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

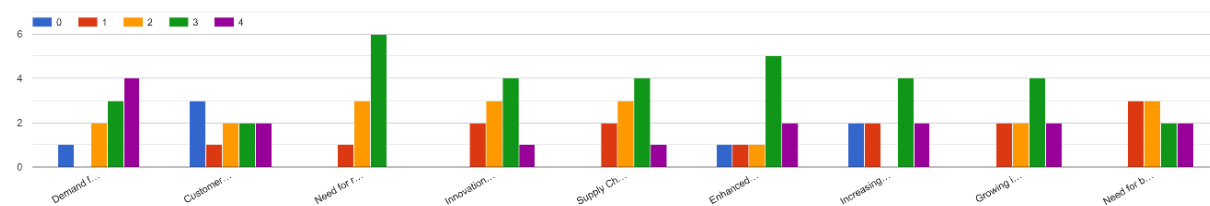


Figure 18: Influence of the “Regulatory requirements for traceability and compliance” factor to the rest.

How does the F7 factor "Enhanced supply chain resilience (risk management) and agility (flexibility)" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

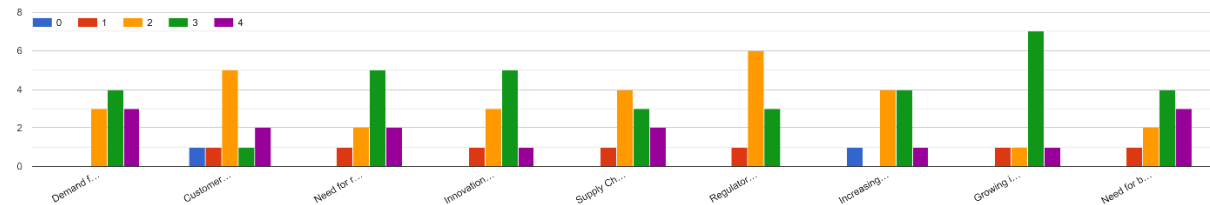


Figure 19: Influence of the “Enhanced supply chain resilience (risk management) and agility (flexibility)” factor to the rest.

How does the F8 factor "Increasing supply chain complexity due to globalization" correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

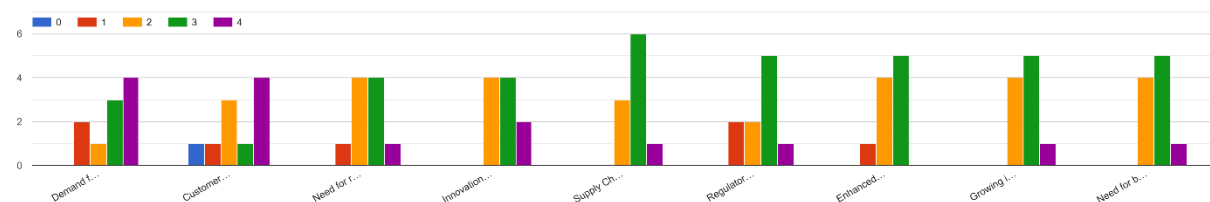


Figure 20: Influence of the “Increasing supply chain complexity due to globalization” factor to the rest.

How does the F9 factor “Growing importance of data-driven decision-making” correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

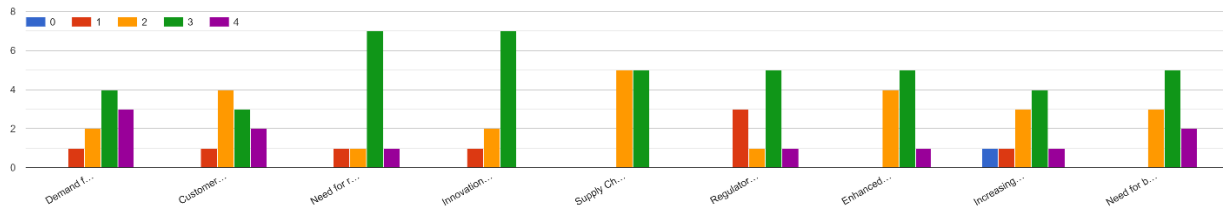


Figure 21: Influence of the “Growing importance of data-driven decision-making” factor to the rest.

How does the F10 factor “Need for better demand forecasting, inventory optimization and process automation” correlates/affects the rest of the factors. Please follow the rating scale: 0: No correlation/effect 1: Very low correlation/effect 2: Low correlation/effect 3: High correlation/effect 4: Very High correlation/effect

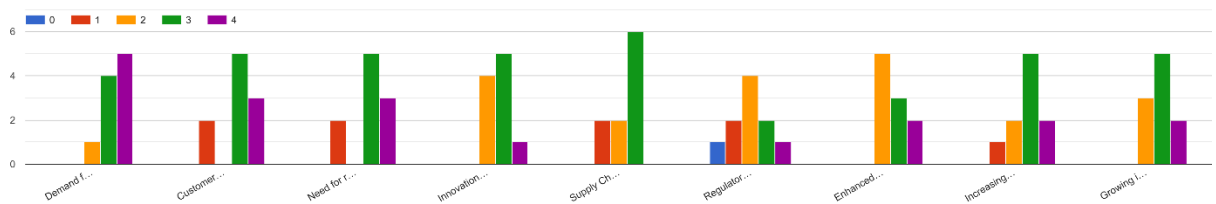


Figure 22: Influence of the “Need for better demand forecasting, inventory optimization and process automation” factor to the rest.

Appendix B: “Single case study questionnaire answer”

Questions for supply chain case study

Company: ##### (for confidentiality reasons the name of the company is excluded)

Offices: Evros, Greece

Sector: Plastic manufacturing

Company size: Medium company with 90 people personnel

Company clients: Europe, Australia, Egypt, Israel

Company supplier base: Europe, Asia

10 years prior supply chain state

- **How would you describe the state of your supply chain operations 5-10 years ago? (e.g., manual, semi-automated, fully automated)**
The state of the supply chain operations can be described as mainly manual, since all the communications with the suppliers and the clients were conducted through mails or phone calls. However, parts of the supply chain were semi-automated, using ERP systems, for inventory management and production, serving as a link between them (warehouse to production). On the other hand, the production state is characterized as semi-automated, since a percentage of the production lines were quite automated.
- **What key technologies or systems were used in your supply chain during this period? (e.g., ERP systems, spreadsheets, manual processes)?**
The main systems used are ERP systems, otherwise most of the processes were handled manually. Furthermore, excel files were used to record different parameters. A low degree of automation existed, since some production lines included robotic arms. However, most of the production lines were manually worked, transferring the product (in different stages) from module to module.
- **Did your company implement any software solutions for inventory management, order processing or logistics at that time?**
The inventory management was supported with the ERP system, while the logistics sector used software solutions. No order processing software was implemented.
- **How were communication and data exchange between different departments and suppliers managed?**
Between the warehouse and the production department communication was supported with the ERP system (inhouse communication) The communication with the external suppliers was achieved with traditional methods such as mails or phone calls.
- **Did you use any data analytics or forecasting tools to predict demand or optimize supply chain processes?**
No.
- **What were the main challenges or limitations in the supply chain due to lack or limited use of digital tools?**

- Delays in orders and deliveries from the suppliers or clients. The traditional processes can slow down the decision-making process across the supply chain. Supplier-production, production-clients.
 - With the absence of digital tools (even as simple as excel sheets) it was difficult to keep track of the inventory levels leading to stockouts.
 - Also, the lack of digital tools result in manually entering or monitoring data increasing the risk of errors and delays.
 - The inability to optimize inventory and production schedules leads to longer lead times, which can increase transportation costs and impact customer satisfaction.
- **Were there any major supply chain disruptions during this period? If yes, how were they handled?**
No major disruptions

Present supply chain state

- **How would you rate now the efficiency of your supply chain processes from 1 (lowest) to 5 (highest)?**
3 → there is a margin for optimization
- **What key technologies, systems or digital tools are currently being used in your supply chain?**
Still using the ERP system as a main tool that supports different processes in the factory such as production, warehouse, invoices supporting a part of the supply chain. A Warehouse Management System (WMS) is installed which supports the warehouse activities and is a vital part of the supply chain offering real-time visibility of the warehouse stock. Also, the WMS has the potentiality to integrate with the ERP system. To facilitate the communications Zoho platform is used for internal and external communication. Furthermore, to further optimize inventory management, barcodes and scanners are being used, automating information upload of inventory/production data to ERP. The productions lines are further equipped with robotic arms automating the process. For real-time inventory checking Cloud Computing is used. To ensure minimum flaws/failures in the delivered products, the factory implements the Batch Numbering process which helps to root back the low quality product in the batch it was produced and check the production parameters.
- **Have you increased the automation level of your processes? Are there any automated systems in place for production, inventory management or logistics?**
Since 10=15 years ago, the automation of the factory has been increased and robotics have been integrated leading to a higher degree of automation in the production lines. The manual product transportation from module to module has been decreased. Relevant information in the above question.
- **Are you using any state-of-the art technology such as Artificial Intelligence, Blockchain, IoT, cloud computing? In which way?**
Only cloud computing is used for real-time data access.
- **Do you use data analytics for decision making in the supply chain?**

Only excel sheets for checking the production and the inventory. Prediction is achieved by checking the demand and the supply of the factory recorded in the excel sheets.

- **How is data collected, processed and shared across the supply chain today?**
 - Through emails for ordering material.
 - Sensors for equipment maintenance.
 - ERP, WMS systems help in collecting data on inventory, production schedules, procurement, and financial transactions.
 - Still sometimes input manually through mobile apps, spreadsheets, or forms, especially for non-automated tasks (like inventory checks or order updates).
 - Cloud platform for internal sharing.
- **How has the digitalization of your supply chain improved efficiency, speed or accuracy?**
 - Better inventory knowledge and optimization
 - Better department communication, with more accurate data, real time data access,
 - Automation of repetitive tasks like inventory updates reducing the need for human intervention. This leads to faster operations and minimizes errors caused by manual processes.
- **How do you communicate and collaborate with suppliers, distributors, and other partners in the supply chain today? (e.g., digital platforms, real-time communication tools)**

Through portals and mails. The supplier has provided portal access to check orders and invoices.
- **Do you have any platforms for real-time monitoring or tracking of shipments, inventory levels, or production progress?**

The inventory level is monitored with the ERP and WMS, while additionally excel sheets are being used. The ERP is also used to check the production progress and correlate the customer demand.
- **Are there any areas where data-driven insights have led to significant improvements or cost savings?**

Mainly for the inventory optimization/management to minimize unnecessary raw material and reduce warehouse costs.
- **What were/are the key drivers to increase the digitalization of your supply chain?**
 - Business evolution and transformation,
 - Customer expectation,
 - Innovation potential,
 - Following ESG factors,
 - Inventory optimization,
 - Supply chain resilience (Ukraine war led to higher prices for raw material purchasing resulting in slightly higher prices for the produced products)

- **Despite digital advancements, what challenges still exist in your supply chain today? (e.g., data silos, integration issues, cybersecurity concerns)**
One of the main challenge, the factory is concerned about right now is Cybersecurity.
- **How have these challenges impacted your supply chain efficiency and cost?**
So far, the supply chain efficiency and cost isn't impacted.
- **Have you thought of implementing best practices such remanufacturing/reuse/....?**
Already the company implements circular practices such as remanufacturing and reuse. Raw materials can be reused, while flawed produced if they can't be remanufactured, will be recycled. These activities are being implemented manually. For example, after quality check, an employee will decide (based on the quality check data) which action to take (e.g. reuse, recycle).

Future supply chain state

- **Do you have a plan (e.g. 5-year period) to further optimize supply chain processes?**
We are going to implement a new system with which the customer can place online his/her order and check the product inventory in the warehouse (order management system). Also, the customer will be informed about potential delivery dates and be able to see the already placed orders. This system will indirectly support the distribution and logistics part of the supply chain giving valuable information to plan/arrange necessary transportation, scheduling staff to achieve the required production to address customer demand.
- **What are your key digitalization goals for your supply chain over the next 3-5 years?**
The company goals are mainly focused on production and inventory optimization, fully automating the production lines.
- **Are there any specific technologies you plan to implement or expand upon in the near future (e.g., AI, automation, blockchain, IoT, cloud-based solutions)?**
Enhance cloud-based solution for data monitoring, integrating also the production data, not only the inventory levels. Fully automating the production lines with the necessary technologies (e.g. more robotic arms). Potentially quality control and maintenance for which state-of-the-art technologies such as AI will be considered.
- **What kind of investments is the company planning to make in digital supply chain tools and technologies?**
Participating in Greek-funded projects mainly in the production and maintenance processes.
- **How do you prioritize which areas of your supply chain to digitalize next? (e.g., procurement, logistics, forecasting)**
The companies main concerns at the moment is in the procurement and logistics part of the supply chain. The type of products (on demand) provides some freedom in inventory levels, since a slight overstocking is not a problem. However, inventory

and production optimization to address the demand is still crucial for the efficient operation of the factory. Forecast is needed internally to maintain the necessary stock to the right amount.

- **Are there plans to further automate supply chain operations? If so, which specific areas will benefit from automation or AI implementation?**

Not right now. Only the mentioned plan/goal in the above question.

- **How do you foresee AI transforming decision-making, logistics, and inventory management in your supply chain?**

There is not a need for AI now, having other areas to optimize first. In any case, having AI to support decision-making could be helpful to better understand the areas we can be better. Maybe, the need will arise in the next years.

- **What role will data and analytics play in your future supply chain strategy? Are you looking to implement more advanced data tools, such as predictive analytics, machine learning, or big data solutions?**

Not right now, because there is no need for it. However, data and basic analytics of inventory and orders is important to organize production.

- **How do you plan to leverage real-time data and predictive insights to enhance supply chain performance?**

We are not planning to leverage real-time data and predictive insights at this moment.

- **Are there any new strategies to mitigate risks, ensure resilience, or deal with disruptions in the digital supply chain?**

The focus is mainly on inventory optimization. Furthermore, the optimal implementation of best practices (also using in the present supply chain digitalization level) such as remanufacturing/reuse/recycle is of high importance to the company since they can support in a degree the company resilience to disruptions

- **Are you exploring new models of supply chain collaboration, such as blockchain for transparency or digital platforms for partner engagement?**

Potentially, platforms for supplier engagement could be useful, to minimize dead time between orders.

- **How do you see digital tools contributing to a more sustainable supply chain in the future?**

Of course, digital tools will help the transformation of the supply chain to make it more efficient and sustainable, however this also depends on the need of the company each time.



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