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# Industry 4.0's Sustainable Impact on Global Supply Chains

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## INTRODUCTION

The biggest challenge society is facing today is the degradation of our environment, which presents complexities and obstacles unlike any seen before in history. Our lifestyles, industrial practices, consumption patterns, population growth and urban development have led to resource scarcity, pollution, loss of biodiversity and global warming. These issues also give rise to concerns such, as the sustainability of our economic system increasing inequalities, social crises and ultimately endangering our survival. Urgent and effective solutions are crucial to prevent consequences. The concept of development has emerged as a response to these challenges with a focus on limiting impacts and addressing long term effects. To tackle these issues effectively society at large must recognize the urgency of the situation – individuals, government bodies and especially businesses all have a role to play. Over the years, the industries have significantly evolved a lot, but unfortunately these changes have often harmed the environment. In today's fast paced era the industrial sector is poised for significant transformation, due to the constant evolution of new technologies. The rise of these technologies has paved the way for Industry 4.0 marking a shift in how businesses operate and produce goods. Amidst this landscape industries are not only tasked with adapting to change but also integrating sustainable practices into their core strategies. The mounting pressure from stakeholders, changing consumer demands and prevailing macroeconomic trends necessitate an embrace of sustainability to ensure long term viability in business operations. Supply chain serves as a network encompassing individual's organizations, resources and processes involved in manufacturing and distributing products or services. Given the array of activities and resources intertwined within supply chains they play a vital role in resource consumption and energy usage. Consequently, they also bear responsibility for emissions and environmental impacts. Embracing supply chain management becomes imperative for companies committed to advancing sustainability initiatives.

As companies increasingly integrate Industry 4.0 technologies into their supply chains this thesis seeks to explore how these advancements can contribute to a sustainable approach, within the supply chain. The initial step involved conducting a review of existing literature to gain insights into the development of Industry 4.0 and sustainability concepts. Subsequently the focus shifts towards identifying the advantages that various technologies like Internet of things (IoT), Blockchain, RFID, Big Data Analytics, Digital Twins, and advanced robotics could offer to supply chain operations. These advancements are seen as key in making supply

chains more agile, transparent and responsive. Drawing from scientific research findings, a critical and personalized analysis will be conducted to address the research inquiry.

Despite the previous research and attention given to Industry 4.0, for its potential to revolutionize supply chain operations, there is a gap in research regarding the sustainable effects of Industry 4.0 on supply chains (Bag et al., 2018; Nižetic et al., 2019). While existing studies have extensively delved into the advantages of Industry 4.0 in streamlining supply chain efficiency enhancing production processes and boosting performance, most focus has been on technological and economic aspects overlooking environmental and social considerations. The aim of this thesis is to understand the incorporation of Industry 4.0 technologies into supply chains and analyse their environmental impact, social consequences and ethical issues that are crucial for ensuring the sustainability of supply chains in the run.

To fill this gap, the following research questions guide the study:

1. What is the impact of Industry 4.0 technologies on enhancing the sustainability of firms within global supply chains?

2. How do Industry 4.0 technologies influence business models in terms of economic, social, and environmental dimensions?

These research questions aim to address this gap by exploring the facets of Industry 4.0 within supply chains with a focus on environmental impact, social responsibility, and circular economy principles. The study will assess the status of Industry 4.0 adoption in supply chain, identify challenges and opportunities for growth and propose a framework, for integrating Industry 4.0 technologies into supply chains in a manner that supports environmental conservation, social well-being, and economic sustainability.

This thesis makes contributions to both academic discussion and practical management by exploring the intricate connection between Industry 4.0 and sustainability, in global supply chains. It provides an understanding of emerging trends, challenges and opportunities that impact supply chain management. Additionally, by offering strategies and recommendations the thesis aims to help organizations embrace practices enhance environmental responsibility and gain a competitive advantage in today's ever-changing business landscape.

The thesis is divided into three parts. The first chapter lays the groundwork by introducing in detail the industry 4.0 technologies and exploring how they are being integrated with sustainability practices in the context of supply chains based on a thorough review of existing

literature. The second chapter builds upon this foundation going deeper into defining a sustainable business model and analysing the inter relationship among digital technologies, supply chains and sustainable business models. Finally, the third chapter explores these inter relationships and aims to answer the research questions through illustrative real-world examples by employing research methods, empirical findings and managerial implications derived from the study.

Through a rigorous and systematic analysis, the goal of the thesis is to illuminate how Industry 4.0 impacts sustainability in supply chains. By combining knowledge with real world applications, it aims to guide decision making, inspire innovation and spark sustainable transformations, across various sectors of the global economy. The findings from the study have the potential to serve as a guide for businesses trying to incorporate sustainability into their business models and simultaneously address the environmental, social and economical impacts of their operations.

# CHAPTER ONE

## Foundations of Sustainable Global Supply Chains in the Era of Industry 4.0

### 1.1 Introduction to Supply Chain

The concept of supply chain (SCM) is relatively new. It has undergone subsequent changes over time resulting in various interpretations. The progression towards SCM can be described as follows. Prior to the 1960s there was a division of tasks and activities across departments within companies leading to sub-optimal outcomes in terms of costs, cash flow and customer service (refer to Figure 1). For example, the concept of balancing the expenses related to warehousing and transportation was not usually taken into account during that period. Subsequently the notion of logistics. was primarily explained within a military context. Logistics encompassed the "acquisition, transportation and maintenance of military resources, equipment and personnel."(Ballou, 2007). In 1964 the concept of "business logistics" was introduced by Heskett et al. encompassing all activities related to supply and material management. At that time companies could incur costs, up to 32% of their sales on logistics and physical distribution (LaLonde & Zinger 1976). This prompted researchers and businesses to recognize the potential for cost reduction by improving management in these areas. Scholars focused on two aspects; coordination of company activities (Ballou, 2007; Heskett et al., 1964) and relationships with external entities and stakeholders (Stevens, 1998; Beamon, 1999; Lambert & Cooper 2000). Over time companies transitioned from logistics to supply chain management through a series of stages, moving from activities towards functional integration to achieve logistics efficiency. This evolution led to the integration of logistics with information services, marketing, and strategic planning, in the 2000s to form Supply Chain Management (SCM) (Ballou, 2007).

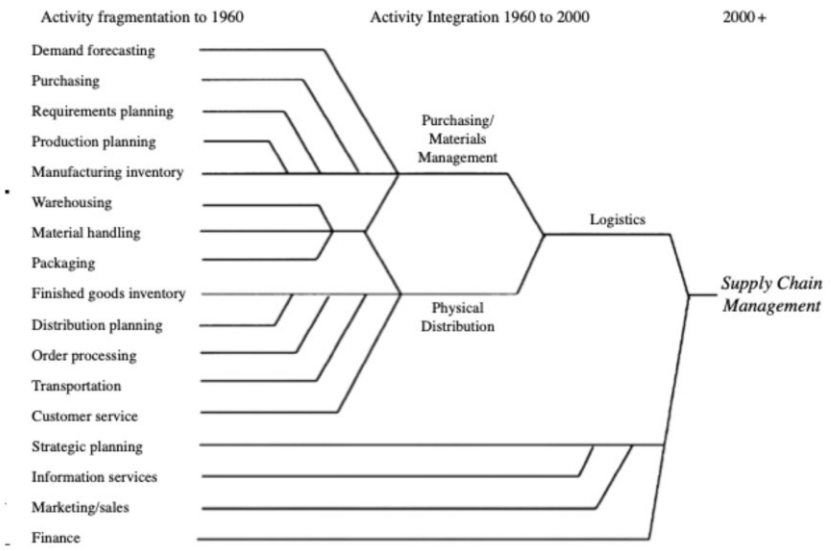


Figure 1. Evolution of SCM. Source: *Ballou, 2007*

Previous research has outlined interpretations of Supply Chain Management (SCM) based on differing philosophies and perspectives (Mentzer, 2001). The Council of SCM Professionals (CSCMP) has defined SCM as the coordination of sourcing, procurement, conversion, and logistics management activities. It emphasises the importance of collaborating with channel partners, like suppliers, intermediaries, third party service providers and customers. Essentially SCM integrates supply and demand management both within companies and across their networks. According to this definition SCM can be characterised by three dimensions; managing activities and processes that encompass logistics operations; fostering coordination within a company; promoting collaboration among different companies in the supply chain (Ballou, 2007). This interconnectedness of different entities in the supply chain ecosystem gives rise to the concept of ultimate supply chain as illustrated in Figure 2 (Beamon, 1999; Mentzer et al., 2001).

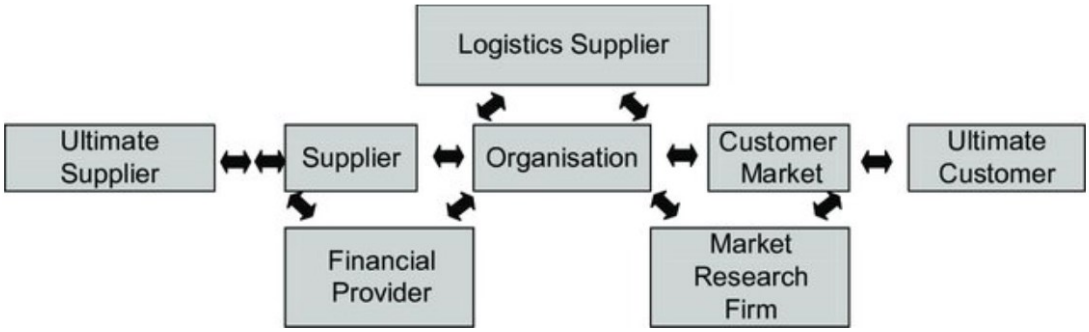


Figure 2. Ultimate supply chain. Source: *Mentzer et al., 2001*

Moreover, shared information and integrated behaviour between different SC entities are fundamental elements for being successful in the competitive global market (Bowersox & Closs, 1996; Cristopher & Peck, 2004; Prajogo & Sohal, 2010) and for establishing a long-term cooperation – necessary to share risks and rewards in the cut throat global market (Mentzer et al., 2001; Thomas & Griffin, 1996). As per the Global Supply Chain Forum (GSCF) Supply Chain Management (SCM) involves linking business processes from end users to suppliers to deliver products, services and information that enhance value for customers and other interested parties. This description emphasizes two elements of SCM. Firstly, it underscores the significance of both material and information flow within the organization with materials moving from suppliers to customers and information flowing in the direction—from customers to suppliers. (Stevens, 1989; Lambert & Cooper, 2000; Mentzer et al., 2001). Secondly the definition emphasizes the importance of providing value. Essentially Supply Chain Management (SCM) aims to achieve an edge by focusing on three elements: cost, cash flow and customer service. As an example, a common objective in SCM could be to reduce expenses while maintaining customer service levels (Houlihan, 1988). This means that companies must make trade-offs among these factors whenever they seek to improve their efficiency (Drucker, 1962) or effectiveness (Mentzer, 2001) to drive profitability (Ballou,

2006; Christopher & Peck; Mentzer et al., 2001). However, due to the nature of supply chain management (SCM) evaluating its performance poses a challenge (Beamon, 1999; Chow et al., 1994). Various frameworks have been developed in the literature each differing in terms of measurement systems and variables considered. For example, benchmarking was introduced by Camp (1989) to gauge performance beyond the effectiveness of variables. Past studies have highlighted two contrasting performance measurement systems; one focusing solely on cost (Cohen & Lee 1998; Lee & Feitzinger; Tzafestas & Kapsiotis 1994) while other consider both cost and customer responsiveness (Altiok & Ranjan 1995; Ishii et al., 1988; Lee & Billington). Both approaches face the challenge of translating qualitative measures into quantitative models (Beamon, 1999). Furthermore changes, in SC models (Meixwell, 2005) and the adoption of technologies have sharpened performance measurement practices by enhancing benefits (Handfield, 1994). Consequently in 2003 the Supply Chain Council outlined five variables. Reliability, responsiveness, flexibility, costs, and assets for or measuring performance in an appropriate way.

In conclusion, the idea of supply chain management (SCM) has changed significantly over the years and continues to do so as a result of various factors, including the intensifying competition in the global market and recent technology advancements.

### 1.2 Evolution of Supply Chain

The development of industries has progressed through a series of revolutions each more complex and productive, than the last. The idea of the Industrial Revolution illustrates a scenario where technological innovation flourishes through creativity making an impact on environmental and social aspects (Fonseca, 2018, p.1).

The beginning of the First Industrial Revolution in the 18$^{th}$ century driven by steam power and mechanization originated in Great Britain—a centre of progress and a powerful trading nation with an extensive colonial empire. This period marked a rise in the use of steam power an advancement that boosted productivity to new levels (Vinitha et al., 2020). Notably the shift from manual to mechanical production methods in the textile industry signalling a crucial change. Alongside this transformation was the growth of businesses and expansion of trade that acted as drivers, for changes. Overall, the First Industrial Revolution ushered in an era characterized by quality of life seen through rising average incomes (Rojko, 2017). The

introduction of steam powered trains enabled transportation leading to urbanization—a defining feature of that time (Groumpos, 2021). The period known as the Second Industrial Revolution also referred to as the Technological Revolution began when electricity was discovered, and assembly line production was introduced incorporating cutting edge technologies of that time. This era was marked by an emphasis, on production made possible by the advancement of new machine tools. Henry Ford's groundbreaking work in revolutionizing vehicle manufacturing embodied this era streamlining production methods increasing efficiency and cutting costs (Sharma & Singh, 2020). The advancements in manufacturing and production technology led to the adoption of systems such as gas and water supply networks, railroad infrastructures and telegraph communication (Groumpos, 2021). Production processes became more intense, competition heightened, and capital played a pivotal role during this transformation (Sharma & Singh, 2020). From 1870 to 1914 the Second Industrial Revolution came to an end with the onset of World War I, marking the end of radical manufacturing approaches (Sharma & Singh, 2020). The Third Industrial Revolution, also known as the Automation Revolution, emerged in the 1970s with a focus, on automation using computers and automation technologies. During this period entire production processes were automated without requiring human intervention (Groumpos, 2021). Programmable machines played a vital role, in revolutionizing production processes making them more flexible, efficient, and safer. Thus, transforming the protentional of automation. This shift from analogue electronics to digital technology had a significant impact on various industries such as communication, energy and engineering (Groumpos, 2021). Decentralization of manufacturing geographies brought supply chain management and the sharing economy closer together, connecting Henry Ford's goal of increasing productivity with the intelligent procedures that define Industry 4.0 (Sharma & Singh, 2020, p.67). We are currently experiencing the Fourth Industrial Revolution referred to as the Digital Revolution. This transformative period is marked using information and communication technologies across industries and societal domains (Groumpos, 2021). Manufacturing operations now heavily rely on computer technology interconnected through networks enabling communication among facilities and promoting self-aware production practices (Sharma & Singh, 2020). This era holds promise for revolutionizing production techniques by digitizing manufacturing environments to enhance efficiency and flexibility through access, to real time information (Groumpos, 2021). These transformative development advances are reshaping industries significantly and will be further explored in following sections.

## 1.3 Global Supply Chain and Sustainability

### 1.3.1 Economic Sustainability

Economic sustainability within supply chains is a multifaceted concept that covers various dimensions like social, environmental and economic aspects (Carter & Rogers, 2008). As emphasized by (Seuring and Müller 2008) sustainable supply chains management (SSCM) aims to integrate these dimensions into business operations and strategies to ensure long-term economic viability while also limiting the adverse effects on society and the environment. At its core the economic sustainability in supply chains aims of generating value not only for shareholders but also for stakeholders throughout the supply chain (Sánchez-Flores et al., 2020). This creation of value goes beyond conventional financial metrics to encompass broader economic indicators such as creating jobs, generating income and economic development in local communities (Seuring & Müller, 2008). Moreover, economic sustainability involves entailing adaptably and resilience within supply chains which effectively helps in navigating economic disruptions and uncertainties effectively (Sánchez-Flores et al., 2020). Through strategies like diversifying sourcing, investing in technology and innovation, and fostering collaboration with stakeholders and suppliers, organisations can secure long-term prosperity and enhance their economic resilience (Seuring & Müller, 2008).

To conclude we can say, achieving economic sustainability in supply chains necessitates a holistic approach that balances financial performance with social and environmental concerns (Sánchez-Flores et al., 2020). Through the alignment of business strategies with proactive engagement and sustainable principles with stakeholders, organisations can foster economic growth and prosperity while minimising adverse impacts.

### 1.3.2 Social Sustainability

The development of supply chain management (SCM) has advanced from focusing on environmental concerns to encompassing a wider range of social sustainability factors. This shift recognizes the interplay, between business operations and the overall welfare of society. As per (Carter and Rogers 2008) social sustainability entails for promoting ethical labour practices protecting human rights and supporting community growth, in supply chains. This

involves ensuring equal wages, secure working conditions and equal opportunities for all employees and stakeholders. Sustainable supply chains prioritise diversity, inclusivity and corporate social responsibility to build relationships within workers, suppliers and local communities. By upholding standards and core values, businesses can build trust, enhance their reputation and create shared benefits, for all involved in the supply chain network. (D'Eusanio et al. 2019) elaborated on how social sustainability within supply chains spans various pivotal dimensions which include human rights, labour practices, community development, and consumer safety and health. These factors underline the pressing importance to promote fair and ethical treatment throughout the supply chain, thus safeguarding the over well-being of all stakeholders involved. (Lee Park et al., 2023) discuss how the integration of social sustainability strategies into supply chains is influenced by a variety of changing factors. These factors include drivers, enablers and barriers. Drivers consist of shifting consumer preferences towards sourced goods increasing investor interest in responsible investments and regulatory mandates. Enablers like organisational leadership commitment and effective management systems support the adoption of sustainability practices. On the other hand, barriers pose challenges, such as navigating the complexities of global supply chains and addressing transparency issues related to supplier behaviours. Despite encountering inherent challenges, the deliberate incorporation of social sustainability principles into supply chains offers a range of advantages which include reducing risks such as expanding market reach and enhancing image improvement.

In conclusion this thorough analysis explains how social sustainability integrated into supply chain management. By looking at its aspects, examining factors and discussing its advantages, this review helps us to understand the importance of social sustainability in promoting ethical business practices. It stresses the need for companies to prioritize integrating sustainability in their supply chains to ensure long term resilience and sustainability in the business world.

### 1.3.3 Environmental Sustainability

Environmental sustainability within supply chains represents a pivotal aspect of modern business operations, reflecting a heightened awareness of the necessity to reduce the environmental footprints linked to industrial activities (Carter & Rogers, 2008). This prioritization of environmental sustainability has gained a significant importance in the recent

times, as organizations strive to harmonize their endeavours with worldwide sustainability objectives and societal expectations**.** A comprehensive understanding of sustainability, in supply chains involves aspects ranging from conserving resources and managing waste efficiently to reducing carbon emissions and protecting ecosystems (Sarkis et al. 2011). This multifaceted approach requires implementing sustainable practices throughout the supply chain starting from sourcing materials to handling disposal or recycling at the end of a products life cycle. One key principle that promotes sustainability, in supply chains is the idea of life cycle assessment (LCA) which examines the environmental impacts of goods or services from start to finish (Carter & Rogers 2008). By utilizing LCAs businesses can identify areas that need improvement and develop plans to mitigate detrimental environmental consequence. These strategies encompass endeavours to diminish energy usage, streamline transportation logistics, and procure materials from renewable or low impact sources. The integration of sustainability efforts, into supply chains is influenced by a combination of external and internal factors. Internal drivers may include cost saving opportunities, corporate environmental policies through resource efficiency and the desire to enhance brand reputation and competitiveness (Seuring & Müller, 2008). Externally driver like consumer demand for eco-friendly products and investors interest in investments play significant roles in driving companies to focus on environmental sustainability initiatives (Carter & Rogers, 2008). Integrating environmental sustainability practices may seem complex but the benefits are significant. By reducing resource usage and waste generation businesses can save costs and improve operational efficiencies, while mitigating environmental risks can safeguard the long-term viability of supply chain operations (Seuring & Müller, 2008). Additionally adopting environmental sustainable strategies can enhance brand reputation attract conscious customers and foster creativity and collaboration within the supply chain (Carter & Rogers, 2008). To conclude we can say environmental sustainability in supply chains is a critical step for modern businesses that are willing to operate responsibly and reduce their environmental footprint. With the integration of sustainable practices throughout the supply chain and responding to internal and external drivers, organizations can reap significant benefits while also contributing to a broader environmental conservation goal. Upholding environmental sustainability principles not only ensures the long-term viability of supply chain operations but also aligns with global sustainability objectives and societal expectations.

As we go beyond into this research, we will uncover how the integration of various digital technologies such as IoT, blockchain, big data analytics, automation, artificial intelligence and digital twin in supply chains impacts all the three above discussed dimensions of sustainability.

### 1.4 Industry 4.0 concept

The current dynamics in the global market create tough competition and require industrial production to quickly adapt to stay competitive. This involves embracing advancements and moving towards Industry 4.0 which originated in Germany in 2011 at the Hannover Fair, the world's largest industrial trade fair. Industry 4.0 represents a pivotal concept driving the adoption of high-tech strategies in German economic policy (Rojko, 2017). Given Germany's presence in the manufacturing industry it's no surprise that Industry 4.0 emerged from this country. Since its introduction Industry 4.0 has gained interest from both academic and industrial sectors. (Rojko, 2017). Industry 4.0 serves as a term for a range of technologies that enable automation, integration, and real time data exchange in manufacturing processes (Koleva, 2018, p.1) At its core Industry 4.0 seeks to introduce new digital technologies' revolutionary power and advantages into the industry's operations and products. (Nicolae, Korodi, & Silea, 2019). This shift in industrial evolution is marked by the rise of factories equipped with intelligent machines and products (Rojko, 2017). In the realm of Industry 4.0 advanced manufacturing facilities are defined as Cyber Physical Systems (CPS) that are interconnected through the Internet of Things (IoT). CPS smoothly integrate, manage and synchronize operations by utilizing real time data bridging the gap, between physical and virtual realms. (Pereira & Romero, 2017). These interconnected intelligent machines, supported by IoT encompass the connectivity of all objects within a factory via the internet (Nicolae et al., 2019). Within the context of Industry 4.0 these smart factories give rise to the creation of smart products. These smart products can independently generate, store and interact with real time data throughout their lifespan autonomously (Schmidt et al., 2015). The fusion of smart factories and products allows for sharing of information among all resources production processes and stakeholders such as suppliers, manufacturers and end users (Nicolae et al., 2019). Industry 4.0, which makes use of Information and Communication Technology (ICT) to improve the horizontal and vertical interoperability of production systems, highlights the future of manufacturing (Nicolae et al., 2019). Competition, among companies sharing

traits in horizontal integration aim to improve production processes by seamlessly connecting materials, knowledge and finances to create innovative business models (Tay et al., 2018). This type of integration is expected to support the development of value creation networks (Koleva, 2018). On the contrary vertical integration involves combining elements like machinery, employees and products within a manufacturing facility and its overall operations. In the context of Industry 4.0 intelligent factories can streamline all activities throughout their value chain using Cyber Physical Systems (CPS) thereby boosting efficiency and adaptability (Tung, 2018). The data. Processed by these machines provide companies with better insights into their operations (Tay et al., 2018). Undoubtedly Industry 4.0 will have an impact, on processes, manufacturing systems and supply chains. It offers increased transparency, optimized resource management and renewed business prospects (Pereira & Romero 2017). Embracing Industry 4.0 enables companies to enhance their edge over other competitors, generate value and manage risks effectively. Moreover Industry 4.0 and the technologies associated with it hold promise in addressing sustainability challenges.

In the next section, we will study and try to identify how their implementation and use can support industries to have a more sustainable supply chain.

### 1.4.1 Industry 4.0 technologies and their impact on global supply chains

When Industry 4.0 was introduced in 2011 it initially focused on a technology, like Cyber Physical Systems (CPS) IoT and Cloud technology. Over time additional technologies were integrated, as illustrated in Figure 3 (Frederico et al., 2019), which outlines the technologies, and their corresponding article counts. Building on existing research and recognizing the significance of these technologies for professionals, this section is dedicated to elaborating on the characteristics of technologies such, as IoT, blockchain, big data analytics, automation (including robotics and digitalization), artificial intelligence and digital twins. It also elaborates on the impacts of these technologies on various aspects of the supply chain, primarily, efficiency, transparency, flexibility and cost reduction.

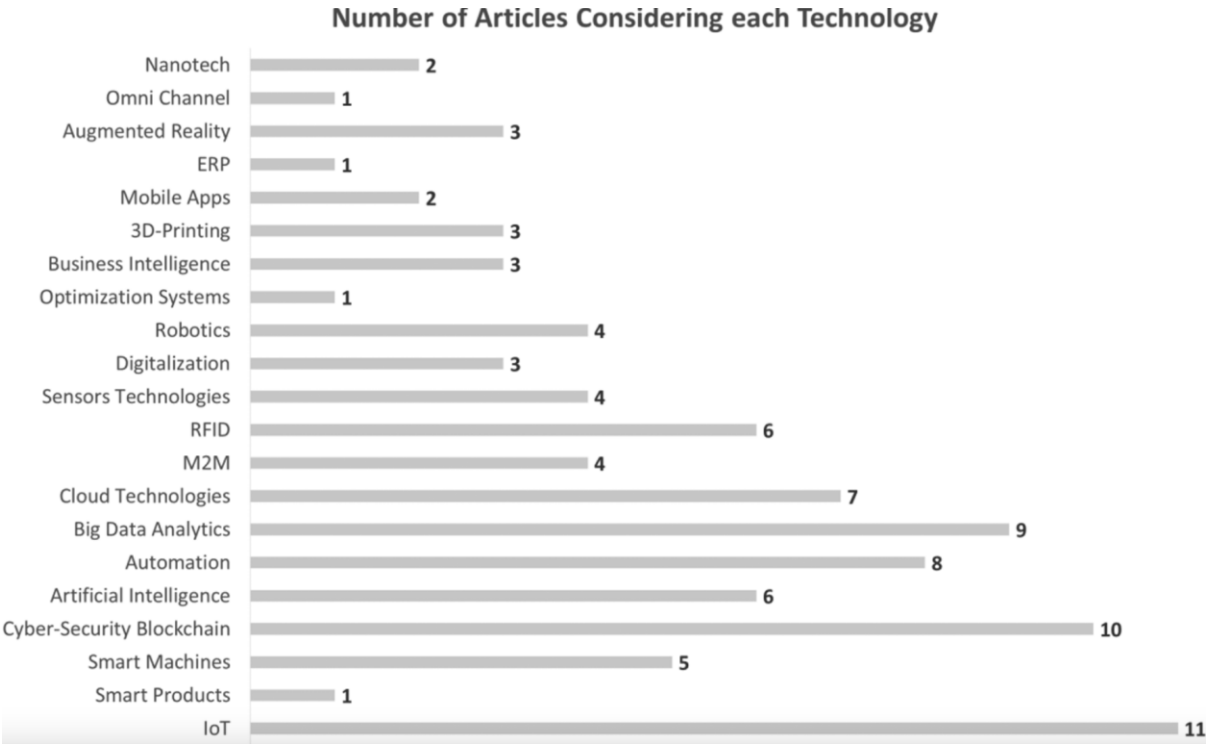


Figure 3. Number of articles considering each technology. Source: *Frederico, 2019*

### 1.4.2 Focus on Internet of Things (IoT)

Since the idea of the Internet of Things (IoT) was first introduced in 1999 there have been interpretations that highlight the elements of the internet and physical objects. This distinction has given rise to two perspectives; one that underscores the importance of the internet aspect and another that focuses on the things themselves (Ben-Daya et al., 2019). According to Ben Daya et al. (2017) they put forward a definition of IoT, within Supply Chain Management (SCM) as a network of connected objects that can sense, monitor and interact both internally within a company and externally across its supply chain. This interconnectedness facilitates flexibility, transparency, tracking capabilities and information sharing to support planning, control and coordination of SCM processes. The term "things" encompasses machines, products or services. The realm of IoT encompasses five technologies: Radio Frequency Identification (RFID) Wireless Sensor Networks (WSN), middleware, cloud computing and IoT applications. These technologies promote communication between machine to machine (M2M) and between customers and machines (C2M) (Lee & Lee in 2015). According to the structure outlined by the Supply Chain Operations Reference (SCOR) model, which breaks

down supply chain (SC) activities, into six stages—planning, sourcing, production, distribution, returns and support—lets delve into the advantages associated with each stage. Integrating Internet of Things (IoT) technology into the buying and sourcing processes brings advantages, such, as enabling real time monitoring of materials strengthening quality control and improving planning abilities (Ben-Daya et al., 2017). Moreover, implementing IoT allows companies to gather data from their suppliers leading to increased flexibility within the supply chain. Key benefits include reduced lead times, better visibility and adaptability enhanced quality and cost-effective product differentiation (Ben-Daya et al., 2017). Furthermore, IoT enhances manufacturing operations by optimizing quality control, maintenance practices, sustainability efforts and production planning and scheduling. This optimization helps reduce times and costs while extending product life spans and increasing profits. The combination of IoT with manufacturing operations offers benefits, across all areas in the manufacturing domain (Ben-Daya et al., 2017). The impact of the Internet of Things (IoT) extends into the delivery process covering aspects like managing warehouses, fulfilling orders, overseeing inventory and handling transportation logistics. IoT applications, in this area enhance safety, security, sharing information, preventing theft and monitoring quality to achieve benefits in terms of time saved, space efficiency, cost reduction and waste minimization (Ben Daya et al., 2017). Nonetheless enterprises face obstacles such as issues with software compatibility, between buyers and suppliers leading to the loss of data and information (Bowman et al., 2009). Additionally, the Internet of Things (IoT) accelerates the adoption of the Kanban approach and lean production principles making reverse logistics and waste management processes more efficient (Ben Daya et al., 2017).

IoT brings about a range of advantages in the supply chain processes, despite facing obstacles during its implementation and incorporation within and between companies. Challenges persist in terms of managing and analysing data, privacy issues and security concerns (Bowman et al., 2009; Lee & Lee 2015).

### 1.4.3 Focus on Blockchain

Blockchain technology has become well known mainly for its use, in cryptocurrencies like Bitcoin, where its effectiveness and safety has been highly praised. Described as a shared and unchangeable record blockchain is used for recording transactions and tracking assets within a

network (IBM, 2022). Assets can be tangible which include items like products or money as well as intangible ones such as intellectual property or copyrights. In essence blockchain functions as a chain of blocks " each holding a record of network activities, such as transactions, documents or data that follow one another after being verified and validated by the block. By employing cryptography blockchain ensures that while adding data is open to all network participants, unauthorized changes, additions or deletions are prevented (Yahiaoui, Fedouaki, & Mouchtachi, 2020). This distinct characteristic of technology guarantees governance and transparency by reducing the risk of data tampering or removal due to its unchangeable nature (Esmaeilian, Sarkis, Lewis, & Behdad, 2020). The widespread use and effectiveness of blockchain technology, in the finance sector has led to an exploration of its potential applications in other fields to make the most of its advantages. Even though its integration into financial areas is still in the early stages blockchain is already being recognized as a major disruptive technology that could transform supply chains by promoting sustainable practices, especially in environmental and social aspects (Tsai et al., 2021). Its ability to bring together all resources and assets within the supply chain adds value to activities, like sharing information, tracking products and improving transaction transparency. As a result, blockchain has the potential to support every aspect of the supply chain, including planning, sourcing materials, production, and delivery processes (Kamble et al., 2021). One of the main challenges faced by supply chains is the issue of visibility. Supply chain visibility refers to the ability to easily track components or products, from their origins from manufacturers all the way to where they end up including all the steps in between without any disruption (Reddy, Gunasekaran, Kalpana, Sreedharan, & Kumar, 2021 p.7). However, the complex nature of multi-tier networks in supply chains makes accessing information difficult especially when companies are striving to ensure the sustainability of their operations and resources. A key feature of technology is its traceability aspect, which allows organizations to simplify how they map out their supply chains by establishing connections between tier-1 and tier-2 suppliers and end consumers. Blockchain technology's fundamental attributes enhance visibility throughout the supply chain promoting increased confidence, among its participants. While traceability is an aspect of blockchain, trust emerges as its advantage in the realm of supply chain management (Paliwal, Sharma, & Chandra, 2020). The transparency and trust provide by blockchain technology serves as powerful mechanism to combat corrupt individuals and address social injustices, including human rights violations, child labour, and corruption, thus advancing social sustainability goals (Munir et al., 2022). Despite the existence of numerous regulations and standards governing these rights, violations remain pervasive. Blockchain

technology can play a pivotal role, in enhancing the aspect of sustainable development by reducing the environmental impact of logistics. While we have previously discussed its importance in ensuring transparency in sourcing materials blockchain also allows for the incorporation of other environmental protections, such as monitoring carbon emissions, energy usage and waste management throughout the supply chain. Essentially, blockchain technology empowers businesses to track carbon emissions leading to a decrease in greenhouse gas emissions and air pollution through traceable analysis (Rejeb, A. & Rejeb K., 2020). Additionally, these thorough analyses help companies to accurately determine the carbon taxes each party should pay while also promoting cooperation and transactions, in green asset markets (Rejeb, A. & Rejeb K., 2020). According to (Kouhizadeh, Sarkis, & Zhu 2019) blockchain technology shows potential, in helping companies identify materials that rely on non-renewable energy sources. This allows them to remove materials from their supply chain that use non-renewable resources or choose alternatives that use renewable sources. Thus, leveraging energy circularity. Additionally, Blockchain technology can streamline stakeholder participation in low-carbon energy initiatives, simplify the implementation of environmental protection programs, and expand consumer access to clean energy (Kouhizadeh, Sarkis, & Zhu, 2019). The blockchain also has a feature where it can store a range of information creating what is known as a digital identity. This digital identity serves as an element, for all involved parties (Paliwal et al., 2020). It enables manufacturers to track their products throughout their lifespan leading to improvements in design, production, sales and product recovery. This enhanced visibility across the product cycle can reduce waste generation and emissions while fostering collaboration among governments, stakeholders and users (Esmaeilian et al., 2020).

The benefits of blockchain technology are numerous. Businesses are still exploring the advantages it brings. It is believed that this technology has the capability to address the issues faced by supply chains and thus making the entire supply chain more sustainable, flexible, effective and environmentally friendly.

### 1.4.4 Focus on Robotics/Automation

The roots of automation can be traced back, to the 1900s particularly highlighted by Fords efforts in factory production. However, the rise of robotics and digitalization has accelerated automation in recent times aiming to streamline every stage of the supply chain from sourcing

materials to final delivery. This evolution signifies a shift, from manufacturing methods as automation now encompasses material flow, data handling, supplier relationships, customer interactions and overall operational controls (Viswanadham, 2002). Nonetheless substantial investments are crucial for companies to successfully adopt and smoothly incorporate these technologies. In the context of supply chain management, automation offers advantages in terms of capacity enhancement boosting productivity, cutting costs, and improving customer service **(**Baker & Halim, 2007). Companies aim to become more flexible and responsive by adopting production methods that can adapt to changes in the market. The use of robotics and digital technologies plays a pivotal role in achieving these goals. For instance, the automation of loading and unloading processes fosters seamless operations while establishing direct connections between different entities along the supply chain, such as cross-docking or vendor-management inventories, helps minimize inventory and delay times (Viswanadham, 2002). Furthermore, simulations play a vital role in identifying potential bottlenecks in warehouse automation (Baker & Halim, 2007). Moreover, automation extends to relationship management, facilitating continuous interactions and leveraging data mining techniques for enhanced efficiency. As per (Sun et al., 2022) Autonomous robots are highly intelligent machines that can evaluate themselves, organizing autonomously and making decisions independently to carry out specific tasks without human involvement. Coming in various sizes and equipped with varying levels of intelligence, mobility and independence these robots are expected to become more common in manufacturing operations especially in supply chain activities like final assembly and warehouse management (Görçün, 2022). Their integration is set to improve the speed and accuracy of tasks, streamline inventory control processes and reduce the likelihood of errors. In addition to enhancing efficiency throughout the value chain autonomous robots offer the potential to greatly improve the working conditions for operators. Primarily used for duties they can contribute to employee's well-being and job satisfaction by allowing them to focus on intellectually stimulating tasks (Kousi et al., 2016). Furthermore, as robotic technology progresses dangerous assignments can be increasingly handed over to robots lessening workers exposure, to environments. Working alongside robots can also boost employee productivity while reducing stress and anxiety levels. Autonomous robots are particularly skilled, at handling tasks that require moving objects easing the burden, on workers and reducing the chances of workplace accidents (Shamout et al., 2022). Another technology that is expected to be talked about more and more these days is Robotics Process Automation (RPA). RPA aims to create software robots, also known as bots, that can mimic human behaviour across various applications (Doguc,2020). (Jain,2019) highlights how RPA has the

potential to improve efficiency of operations across different industries. Similar to robots RPA frees up human resources from repetitive tasks. However, adopting this technology could also lead to generation of reports and data ultimately enhancing process efficiency. For example, RPA can independently generate reports, like revenue projections, inventory status updates, defect analysis, quality control assessments and compliance and audit findings.

Even though automation has a lot of potential for businesses, putting it into practice can be expensive, need multiple projects to operate simultaneously, and may not have user-friendly interfaces. Despite these difficulties, businesses must manage this complexity and make investments in technology that boost productivity and competitiveness to reap the benefits of automation.

### 1.4.5 Focus on Big Data Analytics

The concept of Big Data doesn't have an agreed upon definition. There is a popular framework called the 6Vs that provides a comprehensive view. This framework covers six aspects; Volume, representing the amount of data involved; Velocity, focusing on the quick generation and processing of data; Variety recognizing the various types of structured and unstructured data being handled; Value, highlighting the main objective of creating business value; Veracity, stressing the importance of reliable and accurate processed data; and Variability showing the ability to adapt to new data formats (Chalmeta & deLeon 2020). Big Data Analytics (BDA) can be seen as a collection of tools, algorithms, simulations, and optimizations designed specifically to tackle the challenges and opportunities presented by Big Data (Chalmeta & Barqueros Muñoz, 2021). The use of Big Data Analytics (BDA) helps in gaining knowledge and uncovering patterns and insights, within data. This enables businesses to fully utilize their data resources, extract business insights and make strategic decisions (Ahmed et al., 2018). Big Data Analytics plays a vital role in improving the sustainability of supply chains by monitoring them. By leveraging historical data, it helps to uncover the impact present in a company's supply chain activities. Additionally, through analytics it allows organizations to predict and address sustainability issues promoting ongoing efforts, for improvement **(**Chalmeta & deLeon, 2020). As an example of the automotive industry in a recent survey conducted by **(**Beier, Kiefer, & Knopf, 2020) among automotive industry professionals. Big Data Analytics (BDA) has been recognized as a crucial factor in promoting environmental sustainability due to its

diverse analytical capabilities. Initially BDA helps in measuring energy consumption across the supply chain. By centralizing all energy related data into one database the reliance on systems exchanging information is reduced. This centralized database allows for the establishment of a site energy management system that utilizes BDA to analyse real time data and identify potential energy conservation opportunities. Furthermore, BDA can be utilized to optimize water usage, which essential for processes like cleaning, cooling and painting in automotive manufacturing. Through monitoring of water consumption and effective modelling techniques car manufacturers can better predict patterns of water usage. Operate machinery more efficiently. Lastly, BDA plays an important role in managing waste by monitoring waste quantities and movements to detect trends and conduct analysis using both current and past data. Insights gained from waste data management help evaluate the performance of production lines. Apart from advantages, these analyses also contribute to cost reductions and lower specific production expenses (Hofmann, Neukart & Bäck 2017). Companies which usually have a very large network of suppliers considering the various components and raw materials they need to source; BDA can help them in optimizing their strategic sourcing. This assists organizations to improve their supplier relationship management by ensuring that their procurement processes are aligned to the organization's strategic goals and objectives (Scott, Ho, & Dey, 2013). Big Data Analytics (BDA) offers businesses the chance to improve their risk assessment procedures by examining data points concerning quality, delivery assurances and material availability. Moreover, this technology allows for monitoring data and social media platforms to gain insights into supplier activities and market trends (Wang, Gunasekaran, Ngai, & Papadopoulos, 2015). By combining these approaches companies can effectively assess the influence of procurement decisions on supply chain performance enabling them to make informed decisions. Furthermore, BDA goes beyond cost and profitability assessments to include environmental and social sustainability aspects in supplier oversight. In regions where manufacturing's prevalent due to factors like taxes and labour expenses issues such as environmental degradation and human rights violations may emerge (Zhu et al., 2022). Nevertheless, advancements in information technology make it possible to gather data from each partner in the supply chain empowering management to address these concerns. With regards to considerations, BDA facilitates monitoring of labour related matters like compensation levels, potential instances of forced or child labour use and community exploitation, in locations where supply chain facilities are located (Mageto, 2021, p.6). Chen and Jia (2017) showed that it is possible to choose suppliers by considering factors that used a BDA model to combine information about emissions and waste disposal.

All the technologies mentioned so far allow companies to collect a large amount of data. By using BDA companies can exploit the maximum potential and make better strategic and development decisions with a more sustainable approach.

### 1.4.6 Focus on Artificial Intelligence

Artificial intelligence (AI) has become a common term in our lives. It is now a significant technological advancement. It can be defined as a branch of computer science that focuses on creating systems of performing tasks that traditionally require human intelligence (Kazancoglu et al., 2022). AI technologies aim to imitate human behaviour such as learning from experience and adjusting to situations (Jarrahi, 2018). By utilizing optimization, deep learning and machine learning methods AI has become a powerful tool for advanced data analysis (Mayer, Gandhi & Hecht, 2019). Machine learning, which is a subset of AI uses algorithms and extensive datasets to identify patterns and make predictions allowing systems to evolve and enhance their performance over time. AI is increasingly acknowledged as an asset and is being utilized to enhance various aspects of supply chain management. Its implementation offers the potential for cost reductions and supports sustainability initiatives. It's essential to have thought out plans for meeting demand and managing production to keep supply chains running smoothly (Nguyen, Li, Spiegler, Ieromonachou, & Lin, 2018). Unexpected events and gaps in information can cause fluctuations in demand making it tough for supply chains to stay resilient (Kazancoglu et al., 2022). As evident from the impacts of the COVID 19 companies with complex supply chains have faced challenges in overseeing their demand forecasting process and subsequently managing their production operations. This lack of information often results in discrepancies between supply and demand within supply chain systems (SSCs) leading to communication breakdowns, among stakeholders (Queiroz, Ivanov, Dolgui & Wamba 2020). As a result, traditional demand and supply planning approaches have become inadequate and companies no longer can afford to plan on a periodic (quarterly or annual) basis without compromising the resilience of their supply chains (Koricanac, 2021). In such environment use of AI technology shows promise in closing the gap, between supply and demand utilising real time data to make decisions (Kazancoglu et al., 2022). By improving demand predictions, examining sales trends and pinpointing market prospects AI provides a real benefit to industries. This innovation is truly valuable, amidst shifting consumer preferences empowering businesses to choose wisely with better insights (Mayer et al., 2019). Inventory management

is crucial in industries requiring stock predictions and optimal inventory levels to address operational challenges effectively (Kazancoglu et al., 2022). While traditional decision-making processes based on human judgement may fall short in this regard. Artificial Intelligence (AI) plays a vital role in improving real time inventory management and providing insights into production dynamics. Genetic algorithms, which is one of the sub technologies of AI use data like sales prices, volume and production costs to create models, with least errors enhancing inventory management practices **(**Kazancoglu1 et al., 2022). Moreover, machine learning algorithms help businesses identify inventory trends leading to cost savings and operational improvements. (Tirkolaee et al., 2021). AI technology also provides benefits in predictive maintenance especially by using real time data analysis to predict when machines require maintenance and prevent interruptions in production. Machine learning algorithms are crucial in anticipating maintenance, improving maintenance timetables and ultimately boosting operational efficiency while cutting down on costs related to unexpected downtime (Mayer et al., 2019). Artificial intelligence (AI) also has potential in Research and Development (R&D). During the product development phase of the product life cycle (Schulze Horn et al., 2020). One important use of AI is its ability to help companies consider cost factors and suggest alternative materials with similar features leading to significant advantages and guiding decisions across various departments (Hofmann et al., 2017). Moreover, AI can assist by simplifying the calculation of models using predictions and drawing from data to improve accuracy and efficiency, in decision making processes (Mayer et al., 2017). This technology can also have an impact on promoting sustainability through management of energy usage. By analysing data collected throughout the production process AI can help reduce emissions and improve the practices of businesses (Cioffi, Travaglioni, Piscitelli, Petrillo, & De Felice, 2020). Recent research by (Sishi & Telukdarie, 2021) highlights how AI can optimise supply chain operations leading to decrease in energy consumption and CO2 emissions. In this model the energy requirements of the different business functions were stored in a database. Using algorithms AI focused on managing energy use by determining the most suitable energy levels for each task. This method allowed the company to closely track how each resource impacted energy demands making it easier to identify and enhance processes to lower energy usage (Sishi & Telukdarie 2021). The applications of artificial intelligence are indeed numerous and can offer significant benefits to companies seeking to enhance the efficiency and sustainability of their supply chains.

### 1.4.7 Focus on Digital Twins

According to (Grieves & Vickers 2016), the concept of digital twin is digital information of a physical system that can be generated as an entity on its own, acts as a physical system's virtual counterpart and integrated within the physical system itself**.** Digital twins have become a pivotal technology in transforming the way supply chain management (SCM) operates. They provide a copy of real-world assets, procedures and systems that can be accessed and analysed in real time. This idea as discussed by (Tao et al. 2018) encompasses two elements; the physical object and its digital representation, which are closely linked to enable seamless data exchange and analysis in real time. In the realm of supply chain management digital twins act as models that allow companies to see, track and enhance their supply chain processes at different stages. (Lin et al., 2017). By incorporating sensors, (IoT) devices and advanced data analysis techniques, digital twins assess amounts of information generated by supply chain operations providing valuable perspectives on productivity, effectiveness and possible interruptions. One of the key applications of digital twins in supply chain management (SCM) is based on predictive analytics and scenario planning. Leveraging both historical data and real-time information, digital twins help organisations to foresee and proactively address potential disruptions, optimize inventory levels and thus streamline logistics operations (Tao et al., 2018). Nevertheless, digital twins facilitate scenario simulations, allowing SCM professionals to evaluate the consequences of various strategies and decisions on critical supply chain performance metrics. Moreover, digital twins play a crucial role in augmenting supply chain visibility and collaboration. By providing a consolidated perspective of supply chain processes and participants, digital twins facilitate transparency and facilitate smooth communication and coordination among diverse stakeholders (Lu et al., 2017). This enhanced visibility empowers proactive decision-making and agile responses to ever changing market dynamics and customer requirements. Despite the potential of digital twins in supply chain management many organisations encounter difficulties when trying to adopt and incorporate them. Challenges like merging data, ensuring compatibility and safeguarding against cyber threats present obstacles to successfully using digital twin technologies (Tao et al., 2018). Additionally, the complex nature of supply chain ecosystems and the importance of interdisciplinary teamwork require thorough preparation and financial investment to create reliable digital twin frameworks that suit individual supply chain scenarios.

In conclusion we can say digital twins represent a paradigm shift in supply chain management, providing unparalleled visibility, predictive capabilities and agility crucial for navigating through the dynamic and interconnected landscapes of today's supply chains.

# CHAPTER TWO

## Relationship between Digital Technologies, Supply Chain, and Sustainable Business Models

This chapter begins with an exploration on the impact of digital technologies on economic, social and environmental factors. It sheds light upon how they contribute to the promotion of sustainable practices and operational efficiency in global supply chains. It further proceeds to define what constitutes a 'sustainable' business model, the characteristics of which are explained with the help of a measurable framework linked to a selective list of relevant KPIs. The insights derived from this analysis will offer important perspectives for both practical managerial applications and academic research in the field of supply chain management and sustainable business models. The chapter concludes with an examination of the complexities and barriers that stand in the way of organizations from incorporating the KPIs and frameworks for effective measurement of sustainability levels and the recommendations in overcoming these challenges. These challenges and barriers also describe in detail the issues faced by businesses in incorporating digital technologies into the supply chains and business models for achieving sustainability. In the rapidly evolving industrial landscape, the interconnection of digital technologies, supply chains and business models has emerged as a key area of interest for both researchers and practitioners. This interconnection, if explored rightly, has the potential to transform traditional business operations, and discover the key path to driving transparency, efficiency, and sustainability. Understanding the interplay among these factors is essential for businesses seeking to attain long-term sustainability and simultaneously tackling pressing environmental and social challenges. In this light, this chapter provides a contextual definition of all three elements before exploring the synergy among them.

As examined in the first chapter, supply chains are complex networks that encompass all steps in a product's lifecycle journey. From procuring raw materials to delivering the final product to customers hands smoothly and efficiently is essential, for driving down expenses and improving customer happiness while staying ahead of the competition according to (Mentzer et al., 2001). In order to keep up with the rapidly evolving industries, organizations sticking with outdated supply chain management approaches are often perceived as falling behind the curve when it comes to adapting swiftly to market changes and demands. It is crucial to integrate the digital technologies into SCM to eliminate and address the inefficiencies, lack of

transparency, and environmental impacts. For instance, the adoption of big data analytics into SCM can streamline operations by identifying bottlenecks and optimising resource allocation (Chalmeta & deLeon, 2020). In the same way, digital twins enable the creation of virtual models of physical supply chains, which facilitates real-time monitoring and scenario analysis to enhance risk management and bolster resilience (Tao et al., 2018).

### 2.1 Primary Aspects that Constitute a Sustainable Business Models

Sustainable business models are frameworks that employ strategies to ensure the long-term viability of the businesses through creating a collective positive impact on the environmental, social, and economic aspects. The end-goal of any business is to achieve the 3 Ps of sustainability, namely, Profit, well-being of People and the Planet, and protecting and maximizing their benefits. The three pillars of a Sustainable Business Model, which are the primary aspects that a business model should incorporate into its daily operations and strategies, are explained in this section. These are the environmental, social and economic aspects. In the environmental aspect, the design needs to prioritise environmental responsibility by aiming for minimal carbon footprints and optimising resource usage while producing minimal wastage. The second aspect which is the social aspect encourages businesses to make a contribution to society by upholding fair labour standards and embracing diversity and inclusivity practices while actively participating in community growth initiatives and upholding ethical values with a focus on creating lasting value for shareholders and all stakeholders. These include customers, employees, suppliers and the wider community in equal measure. Finally, the economic aspect requires that the business model should generate consistent profits while simultaneously engaging in innovation and investing in maintenance areas and operational efficiency. The most important aspect to become a sustainable business requires embracing a forward-thinking approach that prioritises long term value over short term gains even if it involves having a trade-off with the short-term gains. This strategy is essential for developing resilience, against market uncertainties and environmental shifts while navigating consumer and competitor dynamics effectively. A prime illustration of sustainable business practices is that of the circular economy approach that focuses on designing products for longevity and recyclability while also highlighting social enterprises that reinvests back profits into community development projects.

## 2.2 Exploring the Synergies among Digital Technologies, Supply Chains and Business Models to attain Sustainability

Understanding the connection between digital technologies and business models involves recognizing how they can work together efficiently. Most businesses can set sustainability objectives that suit their needs and operations in line with the commonly agreed upon concept of sustainable business models. Most of these objectives are now easily attainable through the adoption of innovation through digital technologies, while aligning with sustainable business practices (Seuring & Müller, 2008). In the shift from traditional supply chains to flexible and sustainable systems, digital technologies play a crucial role in offering the essential tools and capabilities. This transition also indirectly supports the adoption of sustainable business models that cater to the three 3 Ps of sustainability, namely, people, planet and profit. When these three elements work together seamlessly and effectively in harmony the business model can operate efficiently with optimized resource management. It also guarantees transparency throughout the supply chain and allows easy monitoring to evaluate sustainability performance using different metrics (Boons & Lüdeke-Freund, 2013), which in turn enables companies to make informed decisions at the right time. In this age where businesses are swiftly adjusting to the ever-evolving global industry landscape, having a solid sustainable business strategy is not just good to have but a necessity for success. This is also the period where consumers are becoming progressively mindful of companies' brand reputation across all fronts with access to a wealth of information about them. Therefore, it's essential for them to incorporate sustainability into their core strategies to guarantee lasting success in a world that is progressively more focused on sustainability concerns. Some recent noteworthy examples include the application of IoT and Blockchain in improving the traceability and accountability of supply chains. This enhances transparency regarding the sustainability ratings of sourcing and production processes. Another admirable achievement is the development of Digital twins to make enhancements by providing insights into the long-term effects of supply chain decisions on sustainability measures (Tao et al., 2018). Similarly, IoT is being implemented in inventory and for the in-store management improvements to offer real time tracking. This aids in reducing waste and gaining insights into consumer behaviour at various stages of a product's journey. It also enhances supply chain visibility (Ben Daya et al., 2017). A majority of the companies are also employing the use of AI and Big Data Analytics to provide insights for accurate demand

forecasting and optimising production schedules (Kazancoglu et al., 2022). The synergy of this triad has emerged as a driving force of innovation and efficiency to enable operational transformation in accordance with the sustainability goals. The contribution and applications of this synergy is multiplying the benefits exponentially by contributing to the environmental, social and economic aspects of a business model and its supply chain. A few of these applications were studied in this research for a better understanding and correlation with the real-world illustrative examples in the last chapter.

The most important sustainability vertical that affects organizations is the environmental aspect. Many organizations are employing digital tools to utilize the wide variety of data available today. The most popular method is the use of Internet of Things for gathering data through sensors placed in equipments, warehouses and other centres. It is important to sort the data in terms of its quality and applicability due to the availability of data in huge quantities and unstructured formats. IoT-based sensors help the companies to categorize this data in terms of what could be called as good data from the noise data to make it more useful. This information can then be analysed by the companies to identify inefficiencies and pinpoint areas for improvement (Ben Daya et al., 2017). For example, refrigerators equipped with IoT sensors can collect information regarding the internal temperature as well as details about the food items such as their expiration dates and quantities remaining. This information enables consumers to make informed decisions when buying goods, thus minimizing waste and regulating energy usage. Companies make wide use of the blockchain technology which operates by storing data in a decentralized manner where every transaction is documented and kept throughout the various phases of the supply chain such as material sourcing, manufacturing and shipping (Saberi et al., 2019). By making all information accessible to all the stakeholders involved, it enhances transparency which enables organizations to verify that all stakeholders including the customers, suppliers, vendors, etc. adhere to environmental sustainability standards while mitigating noncompliance risks. The application of analytics and pattern recognition is crucial in the field of artificial intelligence as it allows for the anticipation and prevention of accidents and failures before they can happen. This proactive approach enables organisations to plan their maintenance activities and make informed decisions about repairs and purchases without risking service disruptions caused by unexpected downtime. For instance, established technology firms such as Microsoft rely heavily on continuous service availability to support their global business operations effectively. AI assistance is valuable for data centre operations as it can predict failures beforehand. This proactive approach helps

prevent energy consumption risks and emissions that may arise from system malfunctions. By taking actions based on these predictions, companies can prolong the lifespan of their systems and minimise the need for frequent replacements ultimately reducing electronic waste generation (Müller et al., 2018).

The second most important vertical that was studied was the social vertical of sustainability factor. The businesses that make use of technologies such as blockchain should ensure that materials and products are used ethically by providing verification processes within the supply chain system. Companies can verify that their suppliers adhere to labour practices and respect human rights by documenting the supply chain activities on a blockchain platform (Tapscott & Tapscott 2017). This transparency allows consumers to choose products wisely and support companies that prioritise ethical sourcing practices. A most impactful example of this is the collaboration initiated by Walmart with IBM to track the supply chain of food products using blockchain technology. Walmart utilises the Food Trust blockchain to trace the journey of its products, like packages of mixed leafy greens all the way from the farm to the store shelves. This method enhances food safety by offering valuable insights into the supply chain that help ensure ethical sourcing and proper handling of products. Digital twins are utilised to gauge the societal repercussions of corporate actions by companies through replicating assets or operations to assess their impact on local communities. The utilisation of a twin of a factory allows for the forecasting and modelling of the effects of various strategies on nearby inhabitants, in terms of altering employment prospects and environmental impact. This tool allows companies to make rounded decisions by considering not just the economic and environmental factors but also their social implications (Grieves & Vickers in 2017). The replication of the real-world physical model into a digital one not only gives the companies the ability to visualize the impact of their decisions and actions on their business operations in the present but also for the future. AI powered tools created for overseeing workforces have the potential to enhance the safety and well-being of employees by monitoring working environments and conditions for possible risks effectively (Zhou et al., 2018). For instance, these systems can analyse information gathered from devices to detect signs of fatigue or stress in workers and take preventive actions to avoid accidents successfully. Moreover, AI technologies provide businesses with the chance to streamline their practices in managing employees and in accordance with labour laws effectively.

The third but one of the most important sustainability aspects that was explored was the economic vertical of the organizations. For instance, IoT applications are useful not only for improving the environmental aspects of a business model's sustainability but also for the economic impacts. These sensors grant companies the ability to oversee the condition and operations of their machinery effectively for upkeep and reduced downtime periods leading to cost savings and enhanced productivity as well (Porter & Heppelmann 2024). Blockchain helps in cutting down inefficiencies and delays in the supply chain by acting as a transparent source of information for all stakeholders involved in the process. This transparency diminishes the necessity for middlemen and more stakeholder by simplifying the transactions and lowering the chances of fraudulence and errors (Min, 2019). Consequently, businesses can attain swifter and more dependable supply chain operation that results in cost reductions and enhanced profitability. AI-driven analytics tools empower businesses to predict demand and supply accurately and to optimise inventory management efficiently by examining past data and present market trends. The AI technology forecasts demand trends to help companies adapt production and inventory levels proactively. This proactive approach minimises the chances of overproduction or stock shortages resulting in cost efficiency and revenue growth (Choi et al.,2018). Digital replicas or twins offer businesses a vital resource for enhancing product and process creativity. Through simulating situations and experimenting with new concepts in a virtual setting, companies gain the ability to pinpoint the most budget friendly and eco-friendly solutions before putting them into practice (Tao et al., 2019). This potential usage of digital twins lessens the duration and expenses linked with product advancement and thus improves the general competitiveness of the enterprise.

### 2.3 Key Performance Indicators for Measuring Sustainability of Supply Chains & Business Models

In today's evolving and resource limited business landscape the incorporation of Key Performance Indicators (KPIs) into evaluations of sustainable business practices is not just a strategic benefit but a crucial requirement as well. These KPI metrics play a vital role in helping organisations quantify, measure and monitor their sustainability endeavours to ensure they are in line with both business goals and stakeholder expectations. By using KPIs, organisations can precisely gauge sustainability efforts which leads to informed decision making, structured improvement initiatives, transparency and accountability in corporate sustainability

endeavours. Customised KPIs enable organisations to adjust and monitor evolving trends in line with industry standards and assess their advancement towards goals. This ability aids in implementing modifications to their strategic planning for long term success by making short term adjustments to reach their sustainability objectives in the long run (Searcy, 2012). For example, when a company monitors its electricity usage in plant units using specific performance indicators to gauge it over time, it can observe the trends over a significant duration of time. Reviewing and compiling a report concerning this can assist the leadership in recognizing areas for enhancement by sources of significant electricity consumption throughout the entire supply chain, if there are abnormal increases. This can benefit the company in reversing the trend, conserving electricity through efficient cost saving strategies. This helps the organization stay true to its promise of promoting sustainability. Measuring sustainability levels of business models with KPIs not only helps in assessing performance but also offers clear visibility and openness to all stakeholders involved, particularly those who are not directly engaged in the daily activities of the company. Quantifying performance allows evaluation by everyone ranging from investors and customers to regulatory bodies when determining how well the firm aligns with sustainability benchmarks. It also allows to establish confidence in the system and instil a positive reassurance among stakeholders by utilising key performance indicators that offer concrete evidence of the company's economic as well as environmental and social influences (Eccles, Ioannou, & Serafeim, 2014). In sectors like oil and gas and automotive industries where sustainability is crucially important for their operations success and image in the market landscape, adherence to KPIs and transparent reporting plays a significant role in upholding a favourable corporate reputation by ensuring compliance with regulations and steering clear of penalties while also positioning them as industry frontrunners in sustainable practices. Therefore, KPIs serve as the mechanism by which companies can translate sustainability objectives from abstract ideas into tangible outcomes that can be assessed, acted upon and documented. Due to mounting expectations for businesses to showcase their dedication to sustainability, the importance of KPIs in upholding responsibility and fostering enduring prosperity cannot be emphasized enough.

## 2.4 Categories of KPIs for Measuring the Sustainability of Business Models

The durability of business models and consequently that of the supply chains involves a procedure that necessitates thoughtful deliberation depending on the nature of the business sector and industry to encompass all potential aspects comprehensively. Different key performance indicators (KPIs) can be grouped according to sectors and classifications. This research delves into a category that holds utmost importance and pertinence, in gauging the sustainability tiers of business models based on conducted studies.

*Environmental KPIs*

These Key Performance Indicators (KPIs) assist in quantifying the business's influence on the environment and ecological systems. For companies looking to reduce their environmental effects and impacts, adherence to international sustainability standards is essential and this can be done effectively through the definition, utilization and monitoring of well-established KPIs. These indicators prioritize how the company's different resources are used efficiently, how the waste and environmental footprints are handled, and how pollution such as carbon emissions, water usage and others are minimized. A set of four significant KPIs were studied under the environmental vertical. The most important one among these is the carbon footprint, which helps in measuring a company's greenhouse gas emissions in terms of carbon dioxide equivalents (CO2e). It covers direct emissions from owned or controlled sources (Scope 1), indirect emissions from the generation of purchased energy (Scope 2), and all other indirect emissions that take place in the value chain (Scope 3) (Wiedmann & Minx, 2008). Reducing carbon footprint is of utmost importance to all the companies for addressing climate change and meeting regulatory requirements. The next most significant KPI that was studied was the energy efficiency KPI. Organisations can gauge their energy efficiency by using energy efficiency KPI's which help in evaluating how efficiently energy is utilised to create goods and services. Often calculated as the ratio of energy usage (measured in kWhs) to output generated (such as revenue or product units). Enhancing energy efficiency helps cut expenses and minimises environmental footprint (Patterson 1996). Apart from these two, the water usage and conservation KPI was also found to play an important role in defining the environmental sustainability aspect of a company. This is used to monitor the water consumption in company operations and evaluate the success of water conservation initiatives in place. These metrics typically include the amount of water withdrawn for use in operations and processes as well as

the amount of water recycled within the system along with water intensity measurements (the volume of water utilised per unit of production). These indicators are adopted practices according to (Gleick (2003). Finally, the waste management KPI assesses the volume of waste produced and the percentage of waste that undergoes recycling or diversion from landfills. Examples of this KPI include the amount of waste generated and the rates of recycling along with the management of hazardous waste (Ghisellini et al., 2016).

*Social KPIs*

Like the environmental KPI category, the social set of KPIs also play an important role in a company's journey towards achieving sustainability of its business operations and supply chain as they help in measuring the business' impact on the society and the stakeholders. Organisations rely heavily upon these performance indicators (KPIs) to establish a strong reputation and safeguard their image from potential risks that could impact their overall performance and competitiveness in the market space significantly. Focusing primarily on labour efficiency practices, community involvement, diversity and inclusivity initiatives upholding human rights standards and effective customer relationship management these KPIs play an important role in promoting positive social impacts ensuring adherence to ethical standards and ultimately enhancing employee and stakeholder loyalty levels. The social sector included four sets of KPIs that were studied as significant. These included the employee health and safety KPI that assesses the frequency, and the criticality of workplace injuries and illnesses occur, using measures like the lost time injury rate (LTIR) and total recordable incident rate (TRIR). These metrics are widely employed to oversee workplace safety and uphold adherence to health regulations (Robson et al. 2007). The diversity and inclusion KPI focuses on tracking the representation of different demographic groups within the workforce, including gender, ethnicity, age, and disability status. For example, the percentage of women in leadership positions or the overall diversity ratio within the company can be key indicators (Konrad et al., 2006). The next identified set of KPIs were the community engagement KPIs which help in assessing how engaged an organisation is with the communities and how much it gives back to the communities that it serves by looking at factors such as the range of community initiatives it backs financially or through employee volunteering time as well as its contributions to community growth and improvement (Epstein & Buhovac 2014). Finally, the last significant KPI that was studied under the social sector was the human rights compliance KPI which measures how well a company follows human rights standards in its business

activities and supply chain management efforts. Key indicators might involve evaluating the percentage of suppliers reviewed for their adherence to human rights regulations and the handling of reported human rights concerns (Schremp Stirling & Palazzo 2016).

*Economic KPIs*

These set of KPIs help in measuring the financial impacts and the long-term economic viability of the business' sustainability efforts. They help the organisations to take appropriate strategic decisions for cost management and budget optimization, make informed investment decisions to improve the investor confidence and attract capital from them by prioritising the ESG (Environmental, Social & Governance) criteria for financial reporting standards. They can be used to measure the value creation through sustainability efforts, which can be easily communicated to the customers, employees and authorities. These sets of KPIs also help in mitigating financial risks associated with factors such as scarcity of resources, changes in environmental and economic regulations, and avoid unexpected penalties, fines and operational risks. Analysing these KPIs will help the businesses in identifying industries where sustainability efforts are valued and hence in achieving a competitive edge and market differentiation. Tracking the financial KPIs to measure sustainability drives of the businesses can greatly help them in managing financial assets and provide them the leverage and opportunity to invest in innovation and new products and services or features to meet the changing customer demands. This can, in turn, contribute to a rise in sales and market share and revenue growth and benchmark their performance against competitors and the industry standards, and identify the improvement areas. A wide set of KPIs were studied under the economic vertical of which the most important ones analysed were the Return on Sustainability Investment (ROSI) which helps in measuring the financial return on investments that are made in sustainability initiatives, such as energy efficiency projects or waste reduction programs and the Cost of Poor Environmental Quality which measures the financial impact of environmental non-compliance, including fines, remediation costs and land revenue due to reputational damage. ROSI is calculated by comparing the cost savings or revenue generated from these initiatives against the initial investment (Esty & Winston, 2009). Managing CPEQ effectively can enhance both environmental and economic sustainability (Schaltegger & Burritt, 2018). The other important KPIs studied in the economic vertical include the supply chain resilience KPI that evaluates the resilience of the supply chain when confronted with disruptions, such as natural disasters or economic crises. The percentage of suppliers possessing sustainability

certifications and the capability of the supply chain to adjust to fluctuations in demand or the availability of resources are some of the metrics that may be considered in measuring this KPI effectively (Sodhi & Tang, 2012). Additionally, the revenue from sustainable products and services tracks the proportion of revenue generated from products and services that comply with sustainability requirements, such as environmentally friendly materials or ethical sourcing practices. It shows how effectively the company can integrate sustainability trends and customer preferences into its business model (Porter & Kramer 2011). The cost savings from waste reduction help in measuring the monetary savings obtained from waste reduction and recycling initiatives and the operational cost savings aid in evaluating the decrease in operational expenses resulting from sustainable practices, such as enhanced utilisation of resources. Finally, the most important KPI that can be understood and analysed by all stakeholders is the customer loyalty and market share which evaluates how sustainable practices and products contribute to customer loyalty and market share growth impacting the aspects positively.

The classification of Key Performance Indicators (KPIs) into social, economic and environmental categories presents a thorough structure for assessing the sustainability of business models. Each grouping provides perspectives into various sustainability facets empowering companies to track their progress across a wide range of sustainability concerns. Using a rounded set of KPIs companies can guarantee that their sustainability endeavours are all encompassing, precise and in line both with their long-term objectives and the demands of their stakeholders. When an organisation focuses on all the KPIs stated under these 4 verticals, it directly improves their emphasis on the triple bottom line, which includes the balancing of profits, people (social responsibilities) and planet (environmental oversight) (Elkington, 1998). This is achieved by implementing circular economy principles, such as designing products for longevity, reusability, and recyclability, thereby extending product life cycles and reducing the need for new resources (Geissdoerfer et al., 2017). These practices foster trust and loyalty among consumers, who are increasingly demanding responsible corporate behaviour. Businesses that effectively integrate sustainability into their operations are better positioned to respond to regulatory pressures, manage risks, and seize opportunities in emerging markets (Porter & Kramer, 2011).

## 2.5 Theoretical Frameworks for measuring sustainability of business models and supply chains

The KPIs discussed in the previous section provide a basic outlook on measuring the sustainability levels of business models and monitoring their success. However, when used in silos, these KPIs are only a theoretical base and do not provide much insight. Hence, it is important to integrate them into a well-defined framework suited to the company and the industry in which it operates. This would help the companies in forming better insights and make informed decisions as per the data and the digital tools. In this context, a detailed analysis was done on understanding the existing frameworks for providing recommendations in this thesis. The most relatable and useful ones identified among these were the SMART framework and the PACT framework. The study first examined the SMART framework and its utilization to measure the economic, environmental, social, and governance key performance indicators (KPIs) for sustainability. SMART stands for specific, measurable, achievable, relevant, and time-bound and these entail the objectives to be attained for each dimension. The study examined in detail how to apply the SMART objectives to the KPIs defined under economic, environmental and social sectors. The table below summarizes the findings from this analysis.

Table 1. Examples of Supply Chain & Business Model Objectives defined as Measurable KPIs

| *Sustainability Vertical* | *SMART Dimension* | *Business Model Objective* | *Supply Chain Objective Example* |
|---|---|---|---|
| Economic | Specific | Establish economic sustainability objectives like cutting down on operation expenses or boosting earnings through sustainable products | Cut down on operational expenses by 10 percent by implementing energy saving methods. |
| | Measurable | Determines performance indicators, including revenue growth, cost reductions, or return on investment (ROI) from sustainability projects | Achieve $500,000 in cost savings from energy-efficient upgrades |

| | | | |
|---|---|---|---|
| | Achievable | Set practical goals based on the existing processes within the company & industry | Reduce the energy consumption by 15% over the next two years, considering current energy use patterns |
| | Relevant | Align financial targets with more general corporate and sustainable aims | Enhance profitability by investing in renewable energy, aligning with the company's commitment to reduce carbon footprint |
| | Time-bound | Establish a precise timetable for accomplishing the financial goals | Implement cost-saving measures and achieve a 10% reduction by the end of the fiscal year |
| Environmental | Specific | Clearly states goals for the environment, such as cutting waste or carbon emissions | Reduce carbon emissions by 20% by switching to renewable energy sources |
| | Measurable | Track environmental performance using quantitative measures, such as emissions levels or waste reduction percentages | Lower CO2 emissions by 50,000 tons annually |
| | Achievable | Set realistic targets based on existing technologies and processes | Implement waste reduction programs to cut landfill waste by 25% within three years |
| | Relevant | Ensure that environmental goals are in line with the organisation's sustainability strategy and regulatory requirements | Reduce water usage in production processes to comply with local water conservation regulations |
| | Time-bound | Give yourself deadlines to meet | Achieve a 20% reduction in |

| | | | |
|---|---|---|---|
| | | your environmental goals | emissions within five years |
| Social | Specific | Establish objectives for social sustainability, such as raising employee happiness or community involvement | Increase the level of employee satisfaction by 15% through enhanced workplace wellness programs |
| | Measurable | Track progress using certain indicators like employee surveys or community impact assessments | Improve employee retention rates by 10% over the next year |
| | Achievable | Set realistic social goals based on current organizational capacity and resources. | Expand community outreach programs to engage 1,000 more participants annually |
| | Relevant | Validate that the organization's values and stakeholder expectations are in line with the social aims | Enhance diversity and inclusion programs to better reflect the community we serve |
| | Time-bound | Set clear deadlines for achieving social targets | Implement new employee wellness initiatives within six months |

Source*: (Ogbeiwi, 2017)*

By using the SMART framework to assess all the aspects, businesses can efficiently gauge and control their sustainability efforts spanning economic, environmental, social and governance factors. Nonetheless, SMART goals might lack a forward-thinking approach geared towards long term success in their perspective. As such, the thesis encourages organizations to enhance their goals by making them smarter through integration with one of the other frameworks which was studied and analysed, namely, the PACT framework. This approach can be seen as an expansion and betterment of the SMART framework. When combined they will support the company in pursuing ongoing development and achieving holistic success. In conclusion, a SMART goal emphasizes the results while the PACT method directs attention towards the output thereby encompassing the entire situation. PACT stands for Purposeful, Actionable, Continuous, and Trackable, the four factors that make for great goals. The goal should be

purposeful, that is, meaningful to the business' long-term purpose, not just relevant for present circumstances. When a goal is aligned with the vision, mission and the objectives of the business, the goals become more meaningful and sustainable. A good goal should be actionable, that is, it should be based on outputs and tasks that are within the scope of the business and should be controllable. The idea is to shift the mindset from distant outcomes in the future to present outputs that the organisation can control and are within their reach, acting today rather than overplanning for tomorrow. It is of utmost importance that the actions taken towards the goal are repeatable and simple. Most of the goals set by organisations are not achieved because of what is called a choice paradox. This happens when there are so many options to choose from that they end up spending more time doing research than actually doing stuff that will help with the progress towards the objective. The good thing about continuous goals is how flexible they are. What businesses need to do is to get started, and as they learn more, they can adjust and adapt their approach. Hence, it involves continuous improvement which eventually helps in reaching a supposed end goal. Sometimes, statistics can be overrated and may not be relevant to various types of objectives. Therefore, when it comes to KPIs, it is crucial to adopt a straightforward yes or no method for tracking goals. For instance, 'Have you reduced operational costs by 15% within two years by implementing energy saving measures and waste reduction?' The answer is a yes or no which simplifies the tracking progress.

The SMART and PACT frameworks complement each other effectively. The use of these in synergy can help businesses to yield optimal outcomes when utilised together. By employing these frameworks companies can pinpoint challenges and objectives through a prioritization method that aids in concentrating on vital tasks. Upon identifying the paramount tasks that closely align with their goals organisations can assign priority to these tasks and channel a majority of their efforts towards completing them before addressing the smaller, less critical ones. An example of a goal for a sustainable business model using both the SMART and PACT frameworks is described to understand the combination better. If the goal is to reduce the energy consumption in operations, the SMART framework defines it as: a) Specific: reduce energy consumption in manufacturing facilities by implementing energy-efficient technologies and practices, b) Measurable: achieve a 20% reduction in total energy consumption compared to the baseline levels from the previous year, c) Achievable: implement LED lighting, upgrade insulation, and invest in energy-efficient machinery within the existing budget and resource capabilities, d) Relevant: supports the company's commitment to sustainability and cost reduction, aligning with our broader environmental objectives, e) Time-bound: complete the

implementation of energy-efficient measures and achieve the 20% reduction by March 31, 2025. Combining this with the PACT framework, the goal is defined in a well-established and goal-oriented format. For instance, the goal should be a) Purposeful: aligns with long-term strategy to minimise environmental impact and reduce operational costs, reinforcing our commitment to sustainability, b) Actionable: implementing energy-efficient equipment and lighting, conducting an energy audit, and educating employees about energy-saving techniques, c) Contextual: the goal addresses assuring compliance and leadership in sustainability, which takes into account the current environmental requirements and industry standards for energy efficiency, and, d) Trackable: progress will be tracked through monthly energy consumption reports, regular audits, and quarterly reviews to ensure milestones are met and adjustments are made as needed. Hence, for this goal, the combined SMART and PACT statement would be: Reduce energy consumption in manufacturing facilities by 20% by December 31, 2025, through the implementation of energy-efficient technologies and practices like LED lighting, upgraded insulation, and modern machinery. This objective is meaningful because it advances our sustainability plan, is doable through targeted training and actions, relevant because it complies with legal requirements, and measurable because it can be monitored by quarterly and monthly reporting.

The SMART framework measures success using metrics that're mostly beyond direct control scope; meanwhile the PACT approach prioritises long term advancement instead. This integrated framework guarantees that the objective is not just specific, reliable and time sensitive but also purposeful, contextual and traceable enabling a holistic sustainability strategy.

### 2.6 Practical Challenges in Measuring the Performance of Sustainable Business Models Using Frameworks

The frameworks mentioned in the previous section provide valuable guidance on identifying and tracking key performance indicators (KPIs). However, when it comes to the practical implementation, companies often face significant challenges. A few of these challenges might have the potential to undermine the effectiveness of sustainability measurement and hence, they stand in the way of the organization from seamlessly achieving their sustainability goals. Hence, it is important that the organizations plan to tackle these challenges. Data availability

and quality is one of the primary challenges in measuring the performance of sustainable business models is the availability and quality of data. Theoretical frameworks such as the Global Reporting Initiative (GRI) or the Carbon Disclosure Project (CDP) rely heavily on accurate and comprehensive data to generate meaningful insights. However, when it comes to reality, most of the organisations struggle to collect consistent and reliable data. This is especially true in the case of multi-national companies that operate across multiple geographies and deal with complex supply chains (Burritt & Schaltegger, 2010). It can be difficult for organisations to assess their actual sustainability performances if the data that they deal with is incomplete or inaccurate, as it can lead to misleading KPI results. This will make it challenging for the companies to make informed decisions. For instance, measuring 'Scope 3' emissions, which includes the indirect emissions also, from the whole value chain (known as ‘Scope 3’ emissions), often requires data from suppliers who may not have reliable reporting systems in place. The total sustainability performance evaluation may be skewed as a result of under- or overestimating emissions due to this lack of data openness (Downie & Stubbs, 2013). The next significant challenge is the alignment of frameworks with business practices. It is often a challenge for organizations to match up their frameworks with the specific operations and business practices they have in place. Many sustainability frameworks are designed with an approach that may not fully account for the unique situations of different companies or industries (Morioka & Carvalhos work in 2016). This misalignment can result in KPIs that are not entirely relevant or applicable to a particular business, leading to difficulties in measuring performance accurately. For example, a manufacturing firm could discover that some environmental key performance indicators highlighted in a framework – like minimising water consumption – may be less crucial to its day-to-day activities when compared to energy conservation or waste handling. This could lead to challenges for the company in customising the framework to align with its sustainability goals ultimately diminishing the efficiency of the evaluation procedure.

The next important challenge that was identified is the complexity of integrating multiple frameworks. Organizations often find it necessary to combine theoretical models to fully grasp sustainability performance across environmental aspects as well as social and economic factors. However, the complexity of multiple frameworks can pose real world obstacles, especially when each framework comes with its own set of methods, metrics and reporting guidelines (Schaltegger & Burritt 2018). The effort required to harmonise these variations may result in added tasks, resource distribution dilemmas and inconsistencies in reporting practices.

A company might choose to utilise the GRI Standards for detailed sustainability reporting and incorporate the SASB framework to satisfy the demands of investors simultaneously. The task of reconciling the varying priorities and metrics from these guidelines could prove challenging as it may result in conflicting approaches for measuring and disclosing sustainability achievements. The dynamic nature of sustainability issues is also a challenge faced by companies. The realm of sustainability is always responsive to various factors like regulatory shifts and market trends that shape it continuously over time. It is a challenge for established frameworks to keep pace with these changes because they might not encompass the recent sustainability concerns or developments (Baumgartner & Ebner 2010). Consequently, companies may discover that the key performance indicators suggested by these frameworks are no longer up to date or adequate for addressing present day sustainability hurdles. For example, the growing focus on biodiversity and ecosystem services may not be adequately reflected in older sustainability frameworks, which traditionally emphasised more established metrics such as carbon emissions or energy use. Organisations that solely depend on these frameworks may miss critical aspects of their sustainability performance, leading to an incomplete assessment. Companies also face resource constraints in the real-world application of theoretical models for assessing sustainability performance. Lack of resources poses a major obstacle. Setting up and upkeeping a thorough sustainability assessment system demands significant financial resources, manpower and technological investments. Small and medium sized enterprises (SMEs) especially face challenges because of limited resources to fully integrate these frameworks which result in gaps in sustainability measurement and reporting (Johnson & Schaltegger 2016). Moreover, businesses may face challenges with resources when operating in regions with restricted access to technology or expertise required for assessing sustainability. These challenges may hinder companies from tracking their sustainability advancements thereby reducing the effectiveness of their sustainability initiatives. In the real-world application of sustainability assessment methods comes the hurdle of limited resources. Making sure a robust sustainability measurement system stays up running demands quite a bit of financial backing along with skilled manpower and technical support in abundance. For small and medium sized businesses (SMEs) this lack of resources could stand in the way of fully embracing these frameworks which could result in incomplete sustainability measurement and reporting practices (Johnson & Schaltegger, 2016).

## 2.7 An outlook on how leading companies have customized solutions for addressing and overcoming the challenges of using theoretical frameworks

Using theoretical frameworks to assess the success of sustainable business models comes with its own set of challenges in real world implementation. Issues related to data availability and quality, alignment with business practices, the complexity of integrating multiple frameworks, the dynamic nature of sustainability issues, and resource constraints can all hinder the effectiveness of sustainability measurement. Organisations must tailor these frameworks to their individual circumstances to effectively monitor their advancement toward sustainability objectives and make well informed choices that promote long term prosperity. Some major international organisations have attempted to tackle these issues by developing tailored frameworks for assessing the sustainability of business models and monitoring and reporting their progress effectively. This approach aligns with the SMART and PACT frameworks overall which can be tailored to fit the specific industry and business type of the organisations involved in order to optimise the potential benefits. These various frameworks developed by companies are customised to meet their needs and operational environments in order to approach sustainability more effectively and precisely. They integrate industry standards and cutting-edge technologies to help companies tackle their sustainability issues efficiently. A few examples of real-world frameworks used by firms to assess the sustainability of their business models have been studied and are explained below.

Unilever, one of the world's largest consumer goods companies, created the Unilever Sustainable Living Plan (USLP) in 2010 to steer its efforts towards sustainability comprehensively. The USLP strives to separate the company's growth from its environmental footprint while also boosting its positive social influence. It focuses on three objectives which include better health and wellness practices, reducing environmental harm and improving livelihood opportunities. The USLP comprises a set of targets in categories like health and hygiene, reduction of greenhouse gas emissions, water use, waste reduction as well as sustainable sourcing efforts and improving the lives of millions of people. Each of the targets involved is backed with particular KPI indicators that are regularly monitored and reported each year. Unilever finds the USLP to be extremely valuable as it matches the company's business goals and brand mission perfectly. By incorporating sustainability, at the heart of its activities Unilever can foster growth and tackle environmental and social issues effectively. (Rangan et al., 2015). Unilever evaluates its performance under the USLP by

monitoring the proportion of sourced raw materials used, the decrease in greenhouse gas emissions throughout its supply chain and the individuals benefiting from their health and hygiene initiatives. These metrics are documented in the company's sustainability report and undergo scrutiny by external auditors. Similarly, IKEA, a global home furnishing retailer, introduced the People & Planet Positive Strategy as its framework to prioritise sustainability efforts by aiming to make a difference for both people and environment through making changes in its entire operational process. From material sourcing to product disposal at the end of its lifecycle. The launch of this initiative in 2012 signifies IKEAs commitment to achieve its vision of becoming climate positive by 2030. The People & Planet Positive Strategy is designed with three areas of focus in mind; inspiring and empowering millions of customers to embrace a more sustainable lifestyle within their homes; striving towards self-sufficiency, in resources and energy; and advocating for equitable and inclusive business practices. Each focus area is accompanied by objectives and key performance indicators (KPIs) that IKEA uses to track its advancement. The framework is useful for IKEA because it is closely woven into the company's business model and operations. It aligns with IKEAs dedication to providing affordable, sustainable products while minimising its environmental impact and advocating for social equality (Engström & Johannesson, 2018). IKEA follows the People & Planet Positive Strategy to monitor how much of its cotton and wood comes from sustainable sources and to track the energy used in its stores and supply chain as well as the progress of renewable energy projects implemented by the company- These measurements are presented in IKEAs sustainability report and serve as a blueprint for its upcoming sustainability initiatives.

Another example that was studied was Nike’s Move to Zero initiative, a step towards creating a future with zero carbon and zero waste. This initiative is a part of Nike’s sustainability strategy and environmental commitment to reduce the impact of their products through innovation in sustainable materials and design practices. Nike’s initiative "Move to Zero" sets out bold goals for the future. These goals include cutting carbon emissions in the company's supply chain by 30 percent by 2030 and aiming for zero waste in Nikes direct operations while transitioning to entirely renewable energy in its owned facilities by 2025. Additionally, the plan emphasizes the importance of using materials which are sustainable like recycled polyester and organic cotton in Nike's product line (Nike annual report, 2020). Nike’s Move to Zero initiative resonates with the company's commitment to innovation and performance goals. By prioritising sustainability Nike can set its products apart in the market, satisfy the demands of environmentally conscious customers and cut down on its operational expenses. (Kiron et al.,

2013). Nike keeps tabs of the amount of sustainable materials incorporated into its merchandise as part of their sustainability efforts and analyses the decrease in greenhouse gas emissions along their supply chain. They also monitor the volume of waste diverted from dumping sites as a measure of environmental impact reduction. These metrics are reported in Nike's annual sustainability report and are used to guide the company's product development and operational strategies.

These real-world frameworks show how top companies measure and oversee the sustainability of their business models in action. Each framework is customized to fit the requirements and objectives of the company behind it ensuring that sustainability is woven into their day-to-day activities and plans. Through embracing these custom approaches these companies not only boost their sustainability efforts but also establish new standards for others in the industry to follow.

### 2.8 Challenges faced by companies for achieving a sustainable synergy among Digital Technologies, Supply Chains & Business Models

The research mainly focused on exploring the significant advantages achieved through the incorporation of digital technologies into sustainable supply chains. It was also important to analyse the obstacles and hurdles that can make the implementation process tricky for organizations and impede progress towards sustainability goals. The major challenge that was observed was the concern about safeguarding data privacy and security risks associated with adopting technology as well as the substantial upfront financial investments required for technological initiatives. As businesses depend more on resources, for gathering and processing extensive data sets and sharing them the safeguarding of this data emerges as a crucial issue. Incorporating advancements like the Internet of Things (IoT), blockchain technology and big data analysis often requires gathering sensitive details regarding supply chain processes and customer relationships as well as employee actions. This information may include business intel, data about individual customers and confidential agreements with suppliers. Safeguarding this data from access, breaches and misuse presents a notable obstacle especially in the face of changing data protection laws such as the General Data Protection Regulation (GDPR), in the European Union (Zhang et al., 2019). The interconnectedness of digital technologies can make them vulnerable to security breaches that cybercriminals might take

advantage of easily for malicious purposes. For instance, IoT gadgets utilised in tracking supply chain operations could get infiltrated by hackers. This could result in data manipulation or operational disruptions (Atzori et al., 2010). Although blockchain technology is typically secure it isn't completely safeguarded against risks like 51% based attacks or flaws in contracts. Companies need to prioritise investing in cybersecurity protocols to safeguard their online systems and data, building and maintaining a digital infrastructure that can be both complex and costly (Kshetri, 2017). Compliance with Data Protection Regulations: Navigating the maze of data protection laws in regions presents an additional challenge for businesses with operations spanning in different jurisdictions. They must juggle compliance with a range of regulations while also keeping their digital supply chain operations agile and effective. Any failure in meeting these requirements could lead to fines and can harm the company's reputation (Nunan & Di Domenico 2013).

The effective incorporation of digital technologies into environmentally friendly supply chains relies not just on the presence of technology but also on the preparedness and openness of the company and its employees to embrace these advancements fully. Adopting technology poses obstacles such as managing transformations effectively, enhancing skills and knowledge levels and overcoming resistance to change. Incorporating the digital technologies into current systems may pose technical difficulties in cases where older systems are obsolete or don't mesh well with modern digital solutions. This could lead to disruptions in operations, data discrepancies and higher expenses. For instance the integration of a blockchain system, with a conventional enterprise resource planning (ERP) system might necessitate custom development and thorough testing to guarantee smooth data transmission and operational effectiveness (Saberi et al., 2019). The upfront expenses linked to integrating digital technologies into sustainable supply chains may pose a significant challenge for small and medium sized enterprises. These expenditures may encompass investing in hardware and software systems as well as creating tailored solutions and recruiting skilled workforce. Digital tools like IoT sensors and blockchain systems along with AI powered analytics and digital twins demand significant financial backing to be implemented effectively within a business setting. The expenses associated with these technologies can differ greatly based on how they are implemented and the intricacies of the supply chain as well as the unique requirements of the organization. Small and medium enterprises (SMEs) often find these costs to be an obstacle, in embracing these technologies as they struggle to keep up with larger corporations that have more financial resources at their disposal (Porter & Heppelmann 2014). In addition to this,

companies need to keep in mind not only the initial investment but also the continuous expenses associated with managing and enhancing their digital technologies such as software updates and hardware replacements as well as ongoing technical assistance requirements that might accumulate over time. Especially, with the constant evolution of technology and introduction of new features these costs can add up (Ross et al., 2016).

In summary, incorporating these technologies into supply chains comes with various hurdles and obstacles that companies need to overcome in order to succeed in their endeavours. These challenges can impede the utilisation of digital tools. To tackle these issues effectively necessitates an approach encompassing strong cybersecurity measures, strategic organisational changes, focused investments in technology and expertise and meticulous planning to guarantee consistency, compatibility and scalability. By overcoming these obstacles businesses can unleash the potential of digital technologies to promote sustainability and bolster their competitive edge. The intersection of advancements with supply chains and sustainable business models marks a significant change in how companies function and compete. This comprehensive strategy enables businesses to enhance effectiveness, equity and eco friendliness by recognizing and utilising the interconnectedness among these components. This holistic approach not only addresses immediate operational challenges but also contributes to broader societal and environmental objectives, ensuring long-term business success in a rapidly changing world.

# CHAPTER THREE

**Research and Sampling Methodologies**

The third chapter discusses the research methodologies employed to analyse the synergy among the business models, their supply chains and achievement of sustainability through the use of digital technologies for different organizations. It further describes the method used for finding the samples which serve as the illustrative examples for the thesis and establishes the scope of the research for better clarification. The chapter is concluded by providing the analysis method and the detailed structure of the analysis used for each illustrative example that was studied in the research.

## 3.1 Research Methodology

Examining the gathered data from the secondary research studies made it possible to evaluate the implementation of digital technologies in today's business operations and identify the similar patterns and anomalies among the theoretical studies and the practical solutions designed and used by companies. These instances provide illustrations of how theoretical ideas are put into practical use as strategies to connect theory with real world applications. This strategy not just clarifies the doubts surrounding tech but also pinpoints effective methods that can be implemented across different business settings (Wamba et al., 2020). Moreover, they shed light on the difficulties in incorporating these advancements such as concerns regarding data privacy and technology compatibility along with significant upfront investment needs (Kshetri, 2017; Min, 2019). Consequently, real life scenarios play a role in propelling not just academic comprehension but also hands-on execution of sustainable business strategies, in this era of digitalization.

Each research method chosen for this thesis has different roles and is selected based on the research objectives as well as suited to the nature of the study, to ensure accurate and reliable outcomes. The research approaches utilized in this investigation are grouped according to their intended use and characteristics and are qualitative in nature. It focuses on exploring phenomena through non-numerical data and aims to understand concepts, experiences, and social contexts by gathering in-depth insights from the selected organizations. The qualitative research methods utilized can be broadly grouped into three major categories, namely, case

studies, secondary research surveys and data and statistics-based analytical research. The first and major part of the research was performed through case study analyses which involved an in-depth analysis of illustrative examples of 5 international organizations to explore complex issues usually faced by companies today and how they are tackled digitally to achieve sustainability in the operations. The secondary research surveys method was used to collect data on attitudes, opinions and mindsets from the chosen list of companies and their business leaders and, in some cases, the collective result of the impact on their business models and indirectly their stakeholders. Finally, a mixed approach of combining the data and insights using a structured format specific to the industry and organization was used as a technique to analyse data and identify relationships or trends and answer the research questions. It was used in the study to examine relationships (differences and similarities) between variables and drawing informed conclusions with contextual insights based on evidence. In most of the case studies and business papers analysed, qualitative data was collected simultaneously with quantitative data, wherever available, and compared to validate and cross-verify results. The qualitative data was collected and analysed first, followed by quantitative data to explain the qualitative based findings.

### 3.2 Sample Selection

The approach taken to select the companies and decide on the sample size for the research study were:

a) Relevant Experience: The organizations must have leveraged innovative digitalization methods in their daily practices or operational processes, with business leaders as well as professionals who can offer valuable perspectives based on real world scenarios and hurdles that they encounter. They must have undertaken projects with strategic relevance to the thesis research objective, that is, integrated digital technologies into their supply chains or operations within the past decade and must be actively engaged in the application of the technology process or provide significant insights into its effectiveness.

b) Leading Position in the Respective Industries: The companies must be leaders in the present or in the past in the respective industry in which they operate in and serve as a role model to the other organizations in terms of digitalization and sustainability targets tied to their

achievements. They must have excelled in their field and have experience in utilizing and applying digital technologies.

c) Diverse applications and large operations scale: To capture diverse perspectives, the companies must be operating globally, in all the major developed countries, with diverse applications and a large customer base and must have industry professionals with wide experience.

Based on these criteria, a list of four multinational organizations spanning various sectors were selected for the study. The sample size was maintained as four to gather a wide array of real-life illustrations while delving deeply into the examination of each individual illustrative example. The selection was done with a focus on achieving a balance among the major sectors, such as manufacturing, retail, and logistics, to obtain a holistic perspective on technology utilization. All the organizations chosen are leaders in their respective industries and have been in the field for more than a decade as well as adopted quickly to the modern digitization methods of operating in a timely manner. Regarding their operation scale, they operate in all the major countries in the world with a large customer and client base, thus allowing for a diversified and comprehensive exploration basis. Three companies were studied individually without comparisons. The study of one company was done as a comparison with another laggard company in the same field which tried implementing digital technologies into the business models and failed due to late entry because of the failure to incorporate digitalization into their working mindset to transition into sustainability. This company was chosen to represent the lack of experience or involvement in the application of digital technologies.

The chosen sample sizes allowed for detailed exploration of individual cases of the selected companies and expert perspectives while ensuring sufficient data for statistical analysis and generalizability. By limiting the number of companies studied to four, a comprehensive exploration of key players in various digital technologies was ensured thereby serving as an enabler to address research questions thoroughly and with expert insights. The companies which had the digitalization plans in their pipeline only in theoretical terms or pilot studies but without real-world applications were excluded from the research.

### 3.3 Scope of the Research

The research was limited to studying the companies and their operations with respect to the digital methods adopted towards efficient operations in short and long-term. However, it is important to note that this thesis does not address areas that delve deep into the technical advancements or engineering elements of digital technologies like programming or hardware design of IoT devices or blockchain platforms. It also does not explore the socio-political consequences of digital technology integration such as regulatory shifts or geopolitical aspects unless they are directly linked to sustainability within supply chains. The study does not consider specific economic metrics such as evaluating the cost effectiveness of technology investments or examining the financial outcomes after adopting them; instead, it concentrates on broader trends and qualitative effects linked to sustainability while setting clear limits to stay focused on these sustainable impacts.

### 3.4 Structure of Analysis

The illustrative analysis on the organizations was done in a structured approach, beginning with the study of the traditional approaches used by them for the supply chain management and business operations, following which a deep dive is presented on the factors and events identified by them that eventually led to their digital transformation process and the rise of disruptive supply chain models. An overview of the projects undertaken and their way of implementation from a high-level is described to provide a basis for understanding the pace at which they moved from the need identification stage to the development of an advanced digitally driven business model, which also helps in analysing the findings and comparisons on the existence of their successful sustainable business models as of today. This also aims to address the challenges faced and the broader management strategies adopted by the companies towards how they tackled the digitalization prioritization proactively, which, if applied to other industrial contexts, can indirectly help the emerging organizations in adapting their approach at an early stage. The findings also help us to understand how these companies have always kept the emerging and potential future trends in mind while developing their business models. An individual analysis of the case studies and a combined data analysis for all is presented, thus allowing for the identification of common themes regarding sustainability, optimization,

incorporating the emerging trends, the adoption of new technologies in the supply chain and business models, and the impact of global digital shifts.

# CHAPTER FOUR

## Illustrative Examples of Supply Chains and Sustainable Business Models using Digital Technologies

The fourth chapter, which is the concluding chapter of this thesis, will reiterate on the gaps in the research and literature reviews presented in the first two chapters by emphasizing the analysis of the outcomes of the organizations that employed digital technologies at the right time to maximize the sustainability of their supply chain management and business models. Addressing this gap is essential for companies looking to build resilient, sustainable supply chains that are aligned with the global shift towards sustainability and responsible business practices. In order to provide a fair comparison, a part of the chapter also focuses on an organization that failed to adapt to modern technologies and the outcomes faced by the company in response to this delayed action. With the findings presented through this chapter, the thesis aims to provide an overview of the digital and technologically sound actions taken by companies, and link this to the analyses and discussions on the subject in the previous chapters. These examples offer valuable insights on the practical hurdles and accomplishments linked to digital transformation, thus providing guidance for companies aiming to utilize technology for sustainable progress.

The chapter serves as a sync between the theoretical world and the practical real-world examples of sustainable business model achievements. These examples provide an in-depth understanding of the most modern solutions that the companies use presently and their adaptations from the traditional outlook that guided their older business models. The exploration has been studied from the point of view of organizations across different industries primarily through secondary research methods with a primary focus on case studies, thereby providing inputs and analyses from different angles, which can be compared to understand the similarities and anomalies of the same subject among various industries. Through these case study analyses, the aim is to arrive at a conclusive and comparative study on how multinational companies have successfully incorporated digital technologies, thereby improving efficiency, reducing environmental impact, and enhancing social responsibility, and their counterparts who did not fare well in the transition towards sustainable business models. The chapter concludes with an outline on the conclusions and recommendations derived from the findings and analyses, with suggestions for future research and how businesses can gain insights into the

practical application of digital innovations and identify best practices that can be adopted by other organizations aiming to advance their sustainability goals.

### 4.1 Illustrative Example 1: General Electric's Digital Transformation and Sustainability Journey

General Electric (GE), which was established in 1892, has long been a pioneer in the industrial sector. It has a history of innovation within the industrial sector and has successfully integrated digital technologies in recent times to stay ahead in the market and promote sustainability practices effectively. By utilizing cutting-edge solutions like the Industrial Internet of Things (IoT) analytics tools for data analysis and artificial intelligence (AI) GE has revolutionized its business processes and product offerings. The examination of GE's use of digital technologies showcases the company's dedication to innovation and sustainability as it strives to lead the industry and meet the increasing demand for environmentally responsible practices. This study explores the impact of GE's range of products and its dedication to technological innovation in establishing its importance in various essential sectors that influence the evolution of worldwide infrastructure and industrial growth over time. By analysing GE's approaches to supply chain management and assessing the results of its progressions in different areas of operations, the study seeks to pinpoint the key elements influencing its differing levels of achievement in attaining sustainability and effectiveness in managing its supply chain and overall business strategy.

GE focuses mainly in the industrial sector, covering areas such as aviation, power generation, renewable energy and healthcare and its offerings are widely used across multiple sectors, such as aviation, healthcare, energy and digital industries. It operates in regions around the world and is a leading player in the aviation industry known for producing jet engines and various aerospace parts that contribute to improving fuel efficiency and performance levels in aircraft technology. In power generation, GE provides solutions for renewable energy sources, from gas turbines to wind turbines, playing a vital role in meeting the global energy demands sustainably. The company has also made strides in the healthcare sector by offering cutting-edge medical imaging and diagnostic equipment that not only elevates patient care but also fosters advancements in medical innovation. It is undoubtedly the unique business model adopted and innovated continuously over the years that has made it possible for GE to

streamline its operations across various sectors on such a big scale. GE's business model approach emphasizes a blend of innovation, sustainability, and ethical practices using digital technologies, mainly, digital twins and IoT across its supply chain to promote sustainability across economic, environmental, social and governance sectors.

*Impact of Trigger Factors and the Need Identification for Digitalization*

GE had long been following its traditional supply chain model like the other companies operating in the same field, and the study identified a few events and factors that drove GE towards its digital transformation journey. These primarily include a few failures that GE experienced in aviation and power generation sectors including turbine failures, unexpected downtimes, high maintenance costs and reduced aircraft availability, thereby highlighting the necessity to implement predictive maintenance solutions. Moreover, with the competitors such as Siemens and Honeywell already starting to focus on digital solutions, the competitive landscape and the customer and client requirements regarding service offerings and equipment performances became the immediate driving forces behind GE's change of operational approach. These events triggered GE to identify the critical need to push for its digital transformation journey and embrace digitalization as a core component of its supply chain and business model. Additionally, GE had already launched its Industrial Internet initiative, for combining advanced analytics and industrial machines, which highlighted the potential of leveraging the opportunity of connecting machines to the digital world. GE recognized that its vast data resources from its industrial machines could be leveraged more effectively. GE saw the potential to implement the use of the digital technology of digital twins to simulate real-world conditions, allowing for better data-driven decisions and began the strategic implementation of digital twins in response to the industry challenges and market demands.

*Proactive Decision-Making and Implementation Approach*

GE introduced its cloud-based platform named the Predix platform as a service for the Industrial Internet, connecting machines, data, people and other assets. This platform aimed to leverage data from machines and create digital twins, allowing GE to monitor performance and optimize operations. Digital twins built by GE had sensors which collected data that would then be incorporated into the digital model, and they were a part of the physical design. As examined earlier in the research, a digital twin is a digital model of a physical object. The physical object has sensors which send data to the digital model. The digital model is employed

to comprehend and analyses the functionality of a machine or system. The digital model was built in a way that it would be continuously updated with sensor data. A digital twin, on the other hand, incorporates real-time data from the physical world through sensors in the real model. In this way, the digital and physical are connected. GE employed the use of digital twins in its aircraft engine industry, by developing digital twins for the engines it manufactures. Built into each engine are hundreds of sensors that record data about the temperature, stress, fuel consumption, speed, and other forces and factors. This data is continuously transmitted and incorporated into a digital twin of that unique engine. Digital Twins was the name created by General Electric to identify the digital copy of an engine manufactured in their factories and are now a reality in several industries. GE used IoT to connect the physical engine to the digital model. GE has complex high-performance systems which require a lot of maintenance and hence, it was important that the downtime be managed carefully and minimized. Through this implementation, GE could monitor the performance of the engine and use this data to improve the performance, efficiency, as well as identify potential problems, all in real time. If they identify an issue in the digital model, they can alert the aircraft maintenance crew to investigate or repair it. In this way, they optimize their maintenance and reduce costly unplanned repairs and downtime.

*Efficient Management Practices for a Resilient Supply Chain and Business Model*

The digital twins help GE even today to predict wear and tear on engine components proactively and help in continuous monitoring to identify any possible failure very early and hence, capture the potential areas for improvements of efficiency. It also helps GE in enhancing the maintenance and repair cycles of equipment or machines. All this was possible, thanks to the long-term approach adopted by GE, by beginning with a careful examination defining what the Digital Twin meant to the company in the first place. The officials defined it as a technology that is clearer when defined by the outcomes it is trying to achieve. Their framework of the digital twin was planned to be composed of either engineering technology, which tends to be process simulation or 3D models, or operational technology, or information technology. In the end, it was agreed to define their digital twin as focusing on enabling the lifecycle of decision-making for field service, integrating operational technology and information technology.

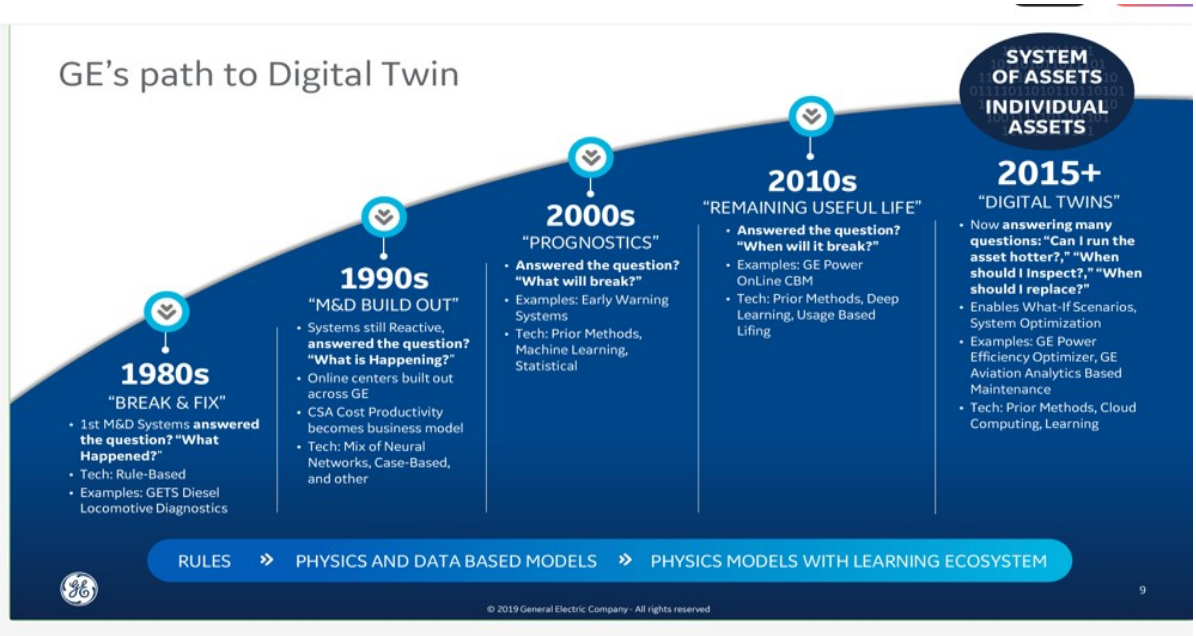


Figure 4. A glance of digital journey of General Electric. Source*: (Irving, 2019)*

*Long-term Planning to tackle the Emerging Trends and Future Challenges*

GE established an industrial software firm, GE digital in 2015 under its umbrella, in collaboration with Amazon Web Services (AWS). With AWS, GE has revamped their data infrastructure across various sectors as an integral part of their goal to enhance the operational efficiency and performance analysis of industrial enterprises. With thousands of worksites and plants requiring maintenance, on-site monitoring can be cumbersome and costly for engineers. This made GE realize the need for a solution for its fleets to leverage technology to communicate remotely, monitor performance in multiple locations, and improve efficiency, all at the same time. GE Company leaders found the solution to this by reinventing their data infrastructure in the cloud. To accelerate the process, GE Digital has been working with AWS to enable a universal, cloud-based platform. The AWS Cloud offers GE Digital the ability to gather, monitor, analyse, and act on data from anywhere in the world. Beyond operational efficiencies, the AWS Cloud also allows GE Digital to deliver an even better customer experience by enabling the scalable infrastructure required to leverage ML analytics to generate predictive insights. When analysing operations in real time, GE Digital can make instant adjustments to boost efficiency and better help local engineers in the field operate wind turbines or other technology with the push of a button. This, when combined with the company's core

machine learning technology has been helping GE in creating digital twins for more than fifteen years, and GE's digital twin blueprint (over 300 types) now has millions of asset-run hours gone through it. This allows the customers to get ROI much faster than their competitors. Since its development, GE has heavily invested in its digital twin development. In the two years following the framework's release, GE constructed over 1.2 million digital twins which generated approximately $600 billion in value for the company and its customers.

GE Research has always been developing technologies relentlessly to make AI more human by giving it a sense of its own capabilities, in a sense, programming it with humility. "Humble AI" refers to the capacity to be able to fall back to a known safe operation mode if the algorithms fail to recognize the scenario or situation. This Humble AI aims to provide a solution to costly consequences such as unexpected equipment downtime and maintenance by predicting downtime and allowing operators to focus on proactively maintaining turbines in the field. The primary idea behind Humble AI was that models will know their competency and areas where they have a high degree of confidence. Ultimately, the promise of humble AI is that it can offer speed to value quicker with less business risk. Although GE has also asserted that this has delivered significant business outcomes for both GE's businesses and customers, our secondary research was unable to find specific client use-cases with stated improvements to their operations.


Figure 5. Example of GE's Predix dashboard for equipment. Source: (*Jarrell, 2021*)

*Impacts based on the Decisions and Actions Taken*

GE Digital utilizes machine learning to assist its clients in reaching their goals through a Digital Twin library—a process that can be up to 75% speedier in certain situations—while also cutting down on reactive maintenance tasks by as much as 40 %within a year's time frame. Moreover, the implementation of machine learning solutions is proving beneficial for GE and its clients in curbing carbon emissions and minimizing energy wastage on the grid. Rather than physically going to a plant or work site to monitor performance, employees can simply log onto the cloud to see how a client's asset is running.


Figure 6. Customer benefits through GE's implantation of digital twins. Source*: (Irving, 2019)*

Operational expenses often cause concern within the industrial sector, but GE Digital software is employed to apply advanced analytics and cut down costs for clients while enhancing operational efficiency through digital twins. Using AWS's industrial cloud platform has proven to be beneficial for GE Digital clients by helping them to cut costs and supporting their shift towards energy sustainability objectives. Examples include the introduction of Competitive Power Ventures, a leading electric power generation development and asset management company in North America, used GE Digital's Operations Performance Management software to increase energy output while managing emissions during periods of high demand—all without costly maintenance adders. Another significant example is that of Xcel Energy, a major U.S. electric and natural gas utility serving millions of customers, which uses GE Digital's asset performance management to prepare for the energy transition by making its plant operations more flexible and agile. Beyond the North American market, La Société Algérienne de Production de l'Electricité, which serves 10 million customers in Algeria, increased the rate of availability of power by 2–6%. This enabled the utility to support

the demand for power when and where it is needed, which is particularly essential as more renewable and intermittent energy sources are integrated into the global grid.

GE has always practised the approach of using the right technology for the right application to ensure the benefit of a fast ROI. GE Digital helped their customers manage more than 8,000 assets in their centre in 2018, the year they implemented it, and this helped generate $187 million of customer documented savings in 2019. The company assisted customers with a range of digital twin applications - for jet engines in flight; submersible pumps in oil wells; turbines on power plants; and packaging palletizing machines in manufacturing and the application and content configuration were carefully crafted differently for every customer and use case. This ultimately resulted in helping customers move from corrective maintenance to predictive maintenance, and hence, aid their customers to take their strategies from being defined once every 5 or 10 years to being defined and optimised in real time.

*Discussion on the Analysis*

a) Work to simplify the complexity: Since complex systems like digital twins require regular maintenance, simply installing an ML solution does not guarantee it will function optimally from the start. It is necessary to understand that success depends on how well the companies perform an orchestration of systems, data sets, and processes. Employees will need to conduct regular asset performance audits, which require adequate onboarding and training. Companies may consider quarterly or yearly check-ins with their client teams to improve retention, tailor the technology to their business goals, and continue to innovate as the market evolves. Through these initiatives, the projects undertaken by GE ensured the long-term resilience and sustainability of its supply chain management practices.

b) Interconnect the digital twins: One solution is not enough to be effective. Multiple ML solutions that work together can generate insights from multiple sources and physical locations. The future of innovation is getting digital twins talking to each other and understanding their language to adapt to various situations. Multiple solutions will render new insights to the customer where a single twin might not. GE ensured that all the sustainability angles were taken care of through the multi-level integration of digital technologies, even including the environmental and social aspects of the business model by ensuring all the stakeholders benefitted from the measures taken.

c) Executive buy-in is vital to change management. The key to long-term customer satisfaction is re-introducing technologies such as AI and ML and its value to new leadership. In the event of staff turnover, connecting leaders with teams that have had the opportunity to work with ML solutions in the past. By sharing legacy knowledge, industry professionals can more easily train newcomers to optimize and manage the technology.

### 4.2 Illustrative Example 2: Unilever’s Digital Transformation and Sustainability Journey

This illustrative example examines the influence of digital technologies on Unilever's supply chain and business approach in the FMCG industry, with a particular emphasis on environmental, economic, social, and governance (ESG) Key Performance Indicators (KPIs). Unilever’s approach to utilizing digital technologies for sustainable growth and transitioning from traditional supply chain practices to digitally driven models is a key focus of analysis in this study. By examining their supply chain strategies and outcomes, this study aims to highlight the key factors contributing to their differing levels of success.

Unilever was established in 1929 by a merger of Lever Brothers and Margarine Unie. It has since become a prominent player in the consumer goods industry worldwide by offering a wide range of products such as food items and beverages as part of its diverse collection alongside cleaning agents and personal care products with operations spanning across more than 190 nations. Unilever stands out as a leading player in the consumer goods industry on a global scale for its effective use of digital technologies to revolutionize how it manages its supply chain and bolster the sustainability of its business approach. A thorough study was conducted to delve into the impact of Unilever's integration of digital tools and dedication to ESG principles on its achievements. This study lays its focus on ways in which digital transformation has heightened efficiency within Unilever’s supply chain while also advancing its goals and commitment towards the environmental, economic, social, and governance objectives.

The fast-moving consumer goods (FMCG) sector consists of products that are sold quickly and at affordable prices like food items, beverage selections, personal care products and household essentials. In terms of the market dynamic within this field, the companies encounter competition and the need to optimize supply chains to cut costs and adhere to sustainability requirements. The integration of digital technologies has become crucial for boosting

operational effectiveness and accomplishing ESG objectives. Companies within the sector are increasingly turning to digital solutions such as data analytics, automation, online retail platforms and blockchain technology to enhance efficiency and promote sustainability. Companies must adapt to changing consumer preferences, regulatory requirements, and sustainability demands. Such transformation is important for maintaining competitive advantage and operational efficiency.

*Impact of Trigger Factors and the Need Identification for Digitalization*

The emerging shift towards E-Commerce and the growth in the sector especially during the COVID-19 pandemic era, led to an increase in online shopping and the organizations in the FMCG were faced with a huge competition because of the necessity of the usage of their products which were daily consumer needs. Unilever had to accelerate its digital presence and establish more efficient E-Commerce logistics. At the same time, Unilever recognized the need for obtaining deeper consumer insights in order to tailor its products and marketing strategies in a personalized manner by leveraging data analytics to enhance customer engagement. The disruptions caused due to COVID-19 helped in unveiling the multiple vulnerabilities in the traditional supply chains of FMCG companies including the leaders like Unilever thereby prompting them to invest hugely in digital technologies to provide modern solutions for enhanced visibility and better flexibility. Unilever's business model identified the need to emphasize its focus on innovation, efficiency, and sustainability, leveraging digital technologies to enhance its supply chain operations and support its strategic goals. It acknowledged the need to use digital solutions to achieve promising results of streamlining operations, reduced lead times and manufacturing costs. This, in turn, would yield better distribution processes and efficiency across the entire supply chain and aid towards improved tracking of sustainability metrics, aligned with Unilever's sustainability commitments.

The other major factors that triggered Unilever in shifting quickly towards digitalization were the emergence of digitally sound competitors who were already developing advanced solutions, despite being late entrants into the market, such as regional and local players in FMCG. Unilever also recognized the potential of digital platforms to facilitate faster development cycles, allowing them to respond quickly to the market trends and consumer demands, and stay ahead of the competition by acting proactively. Additionally, enhanced communication and collaboration tools became quite essential for remote work and efficient coordination across global teams. All these factors collectively contributed to the on-time approach adopted by

Unilever to innovate its supply chain to incorporate changes as per the digital trends, to remain relevant and leading in the market. This played a critical role in shaping Unilever's strategic shift towards a more integrated and digitally enabled business model.

*Proactive Decision-Making and Implementation Approach*

The identification of the need to shift the approaches to digital methods at an early stage helped Unilever succeed in incorporating various technologies such as artificial intelligence (AI) and AI-based data analytics into its supply chains and business models. Unilever used AI and data analytics extensively to propel its digital evolution and enhance different facets of its business activities. The company applied these technologies to enhance decision-making procedures, optimize supply chains, improve marketing strategies and create personalized consumer experiences. This approach helped Unilever build a more sustainable business model as compared to other players in this industry. Unilever's successful journey was examined by looking into the digital initiatives and sustainability projects they have undertaken and analysing their impacts.

Unilever began the implementation of the Project named SAP HANA with a platform to oversee its enterprise resource planning (ERP) systems effectively. Leveraging this cutting-edge technology accelerated the data processing speed significantly and helped in cutting down the time needed for tasks like financial closing from hours to minutes. This advancement facilitated instant data analysis that was pivotal for making decisions and formulating strategies. It assisted Unilever in modernizing its operations by incorporating state-of-the-art technologies through the utilization of the digital SAP platform. This transformation focused on streamlining ERP systems and refining the efficiency of supply chain operations. It also helped in enhancing financial processes and increasing agility to better respond to market needs.

Unilever utilized a conceptual framework known by the name Digital Capability Framework (DCF) within the platform of SAP HANA to guide its transformation process and prioritize areas for enhancement effectively across six dimensions, namely, Customer Centricity, Effective Knowledge Worker, Operational Excellence, Transformation Capability, Innovation Capability and IT Excellence. By aligning its IT strategy with business goals based on these dimensions, Unilever was able to boost its capabilities significantly. Embarking on the implementation of SAP HANA marked a significant step for Unilever as it aimed towards

elevating its digital processes and streamlining operational efficiency on a global scale. The main goal was to move all ERP systems to SAP HANA in order to create a business that is more flexible and can respond quickly in real-time situations.

Unilever aimed to streamline over 200 local ERP systems into four regional SAP setups as part of its strategic plan. The goal was to boost operational efficiency and support the company's growth targets by simplifying operations. The initial phase of SAP HANA implementation began with a proof of concept in the finance area, focusing on accelerating the controlling and profitability analysis. Unilever effectively implemented this in 2012 across all four ERP setups and ended up significantly improving the speed and quality of financial reporting.

*Efficient Management Practices for a Resilient Supply Chain and Business Model*

Unilever's Sustainable Living Plan (USLP) was established by Unilever's management in 2010 as a strategy for embedding sustainable practices throughout Unilever's operations and supply chain. It has developed immensely and has now become a core element of the company's business approach by focusing on fostering sustainable development through addressing environmental, social, and governance (ESG) impacts across its global operations. The objectives were clearly defined by the management and were inclined towards achieving sustainability in the supply chain and business model through heavy investments in digital technologies. One of the objectives was to reduce the environmental footprint to lessen the impact of its products on the environment. The USLP aims to cut Unilever's products environmental impact in half by 2030 by decreasing greenhouse gas emissions and reducing water usage and waste generation throughout the entire value chain, from sourcing raw materials to consumer disposal and use stages. Digital tools like IoT sensors and AI analytics were identified as essential in overseeing and optimizing energy and water consumption in real time while also pinpointing waste areas and streamlining production methods for higher efficiency, with minimal resource consumption. The other major management practices defined for building a resilient supply chain were to advocate improved health and wellness through Unilever's business strategy and promote human rights and generate economic prospects throughout its operations network. Digital tools, which had already been proven to empower Unilever to maintain transparency and responsibility in its supply chain operations, were used to closely monitor labour standards and interact with communities to promote farming practices and ethical sourcing. This ensured the social dimension of sustainability was considered seriously. By harnessing the power of data analysis techniques, the company is now

more capable of evaluating the outcomes of its projects and using data driven insights to enhance them further. Additionally, Unilever rightly recognized the need of the governance factor to create an all-round robust system of implementing USLP by upholding environmental and social regulations effectively. In order to do this, Unilever leverages blockchain technology to improve transparency and traceability in its supply chain operations to guarantee sustainable sourcing of materials. This digital approach to governance helps mitigate risks and ensures adherence to the highest standards of corporate responsibility.

*Impacts based on the Decisions and Actions Taken*

The implementation of the SAP HANA project and USLP yielded substantial quantitative and qualitative benefits. The major among these was a substantial reduction in the financial closing time. After incorporating SAP HANA into their system Unilever managed to cut down the time required for financial closings from 3 to 4 days, to just a couple of hours. This was a remarkable enhancement that not only saved the company around 50,000 person hours every year but also resulted in substantial cost reductions. With the help of SAP advanced planning and optimization was performed by Unilever and this helped to optimize production planning and scheduling, enabling an estimated additional capacity for daily sales orders valued at approximately 6.8% more than before. This optimization was expected to increase on-shelf availability (OSA) by 0.5%, translating to a potential revenue increase of €125 million and an additional margin of around €50 million. The SAP HANA project also brought changes to how Unilever operates by helping them make better decisions and improve their operations overall. By shifting to SAP HANA technology, Unilever was able to analyse large sets of data instantly leading to more precise predictions and improved coordination between supply and demand. Their upgraded analytical tools enabled smarter business choices that enhanced efficiency throughout the supply chain resulting in improved customer service through better planning and scheduling. Combining data from different sources into one platform enhanced the consistency and accuracy of information which resulted in more dependable reporting and analytics capabilities. This enhancement supported improved planning and risk assessment.

The integration of advanced planning and optimization with this project significantly improved Unilever's ability to forecast demand and optimize production schedules. This led to an increased customer satisfaction through better product availability and reduced costs by minimizing excess inventory. The digital transformation helped Unilever in improving its cost structure, enhance its agility, and support sustainable business growth. By integrating digital

technologies, the company was able to better manage its supply chain, reduce its environmental footprint, and improve overall business performance. The use of real-time data and analytics allowed for more responsive and adaptive operations, supporting Unilever's goal of doubling its business while reducing its environmental impact.

The USLP project also helped Unilever in achieving reduced greenhouse gas emissions. Ever since Unilever introduced the USLP program, there has been a 75% reduction in CO2 emissions from their production operations compared to the starting point in 2008. This achievement is largely attributed to the adoption of renewable energy sources and energy efficient technologies such as AI powered systems that monitor energy usage in real time and identify areas for improvement. Since 2008, Unilever has lowered water usage in its manufacturing operations by 49 percent, per ton of production since 2008 by using digital water management systems to oversee and enhance water usage efficiency while reducing waste and encouraging water reusing. The company has also successfully met its goal of eliminating non-hazardous waste sent to landfills across its worldwide factory network in 2015 through the adoption of digital resources to monitor and control waste streams and the utilization of machine learning algorithms to pinpoint recycling and waste reduction possibilities. Unilever has enhanced its relationships with suppliers and communities by utilizing platforms that prioritize transparency and traceability in their operations. These efforts aim to foster ethical practices across Unilever's supply chain. The implementation of blockchain technology has been particularly impactful as it allows Unilever to track the sources of its palm oil and tea products. Such measures guarantee that these resources are procured in a manner that upholds rights and environmental preservation.

*Challenges and Innovations*

When talking about the success of the projects undertaken by Unilever, it is also important to highlight the challenges and drawbacks faced by the organization while implementing them. Adopting the SAP project was met with its own set of obstacles such as the requirement for significant upfront capital and the intricacy involved in shifting current systems to the updated platform. However, this was countered by a targeted approach focused on restructuring business operations to make the most of the new technology. For instance, Unilever utilized design thinking to identify areas of opportunity in the supply chain, ensuring that the transition to SAP HANA was not just a technological upgrade but also a catalyst for broader business transformation.

*Discussion on the Analysis*

In terms of looking at the bigger picture of things, Unilever's implementation of SAP HANA showcases a thorough plan to boost its digital capacities by optimizing supply chain management and fostering innovation – setting an example for utilizing advanced ERP solutions to spur business growth and sustainability in the consumer goods industry. Unilever's transformation into a real-time digital enterprise has established it as a leader in digital capabilities within the consumer goods field. The strategic application of digital technologies supported by the Digital Capability Framework has enabled Unilever to unlock significant value and improve operational efficiency while driving growth. The case study highlights the importance of aligning IT strategy with business goals and consistently seeking out ways to remain competitive in a swiftly evolving market. Unilever's use of the SAP HANA acted as a catalyst in their journey towards becoming an integrated digital enterprise in real time settings. The upcoming phases of development at Unilever could involve expanding these setups globally to all markets they operate in. Utilizing SAP HANA's cloud capabilities for quicker innovation and further embedding digital features throughout the business are also key aspects being considered to sustain growth and stay competitive by Unilever. This ongoing digitization effort is aimed at supporting Unilever's growth strategy by enabling responsive and flexible operations that closely align with market needs.

Apart from the SAP project, Unilever's USLP showcases the role of digital technologies in revolutionizing supply chain management and enhancing the sustainability of business models by emphasizing key performance indicators related to the environment economics, social and governance aspect. This initiative sets a standard for corporate sustainability by utilizing digital technology to foster ongoing enhancements and creativity throughout its worldwide activities.

The table below summarizes the future actions based on the study and findings, that can be undertaken by Unilever to achieve the complete successful integration of digitalization into their business model and operational sustainability efforts. Other companies in the same field could also use these recommendations and insights to develop their business models to progress towards their sustainability goals.

Table 2. Recommendations of Future Strategies & Initiatives for Unilever

| Broad Strategy | Detailed Explanation of the Initiative Proposed |
|---|---|
| Scaling Digital Innovations | Adopt a plan of action to increase the utilization of digital tools to improve transparency and efficiency in their supply chain operations. The strategy involves implementing AI and machine learning technologies to streamline logistics processes reducing wastage and enhancing the allocation of resources to achieve sustainability goals more efficiently. |
| Expand Sustainable Sourcing | Ensure that all its agricultural raw materials are sustainably sourced by the year 2030 with the help of digital tools that offer real time insights into supplier practices and allow the company to confirm adherence to sustainability standards throughout its worldwide supply chain. |
| Enhancing Product Circularity | To promote the shift towards a circular economy, it is necessary to invest in digital tools to monitor the entire lifespan of its products from creation to disposal. Aim to reduce waste and encourage recycling while ensuring sustainability is integrated into product design right from the start. |
| Strengthening Governance and Compliance | Utilize digital technologies to strengthen the governance practices and uphold strict environmental and social regulations across the entire life cycle of operations. This involves employing predictive analysis for early detection of compliance issues and adopting blockchain technology to ensure transparency and responsibility, in the supply chain management processes. |

Source*: Personal elaboration of author*

### 4.3 Illustrative Example 3: Patagonia's Digital Transformation and Sustainability Journey

The previous two case studies were based on organizations operating in industries which are well-known for being fast paced in their commitment towards business and supply chain sustainability goals. Their customers and clients form an impression and judgment about purchasing from them based on the outlook that those companies have among the public regarding their ethical and sustainability efforts. However, an industry where customers are not hugely bothered when it comes to purchases and staying loyal to the brands is the clothing and fashion industry, at least as of today. Hence, if an organization is committing towards well-defined sustainability goals and staying loyal by putting efforts into them in this industry, it is a huge indicator that they are truly committing to the supply chain and business sustainability for the right purposes, and not just for the brand image and staying relevant. The company that was analysed here is Patagonia, a leading outdoor clothing brand that has set a standard for incorporating digital innovations in managing its supply chain and promoting sustainability initiatives. This analysis delves into how Patagonia has employed digital solutions and followed environmental and social governance guidelines to improve its business approach and daily functions. The discussion centres on how these strategies have played a crucial role in Patagonia's success.

This research aims to investigate the methods that Patagonia has utilized to enhance sustainable growth through digital technologies. The analysis of their shift from traditional supply chain management and business models to modern and efficient business practices driven by digital technology was conducted in order to assess their impact on sustainability objectives and identify key factors influencing the varying levels of success achieved by Patagonia in this regard. The outdoor clothing industry consists of companies that create apparel and equipment for pursuits like hiking and skiing while also contending with competition from well-known brands and emerging players. These companies must consider both product quality and sustainability as consumers are increasingly starting to demand environmentally friendly and socially responsible products. Digital advancements and technologies like e-commerce platforms and AI are being adopted by the industry to improve supply chain efficiency and foster a sustainable business approach. In this context, it is significant to mention that Patagonia

has always been known for its commitment to environmental sustainability and social responsibility since 1973, when it was founded. It operates globally with a strong focus on producing high-quality, durable products. Patagonia's approach to business has always strived to highlight creativity and ethical values while also prioritizing sustainability efforts in their operations by utilizing digital technologies.

*Impact of Trigger Factors and the Need Identification for Digitalization*

Patagonia's shift from the traditional supply chain management methods towards applying modern digital solutions was triggered due to many factors. Since the early 1970s, Patagonia has been supplying climbers, surfers, fishermen and lovers of the great outdoors with high-quality clothing, tools and equipment. The administration of its budgeting process has always been quite time-consuming and involved combining data from 25 separate planning models due to its globally wide operations. Hence, very early on in its journey itself, Patagonia recognized the need to improve visibility of actual and planned global inventory levels across its wholesale, direct and retail sales channels, and to reduce the administrative overhead of the budgeting process. They acknowledged the necessity of a budgeting application that was faster and more flexible and more easily maintainable, to be easily developed and controlled by the finance team. Patagonia also realized that the application should be able to handle deployment to more than 100 contributors across the globe and be able to provide training easily and seamlessly to its widely scattered users. Unlike most companies operating in the sector, they incorporated long-term planning into their working mindset and through this project, they were also investing in an inventory forecast model solution for attaining better visibility of their future global inventory levels at a detailed style and colour level in a region-wise manner.

*Proactive Decision-Making and Implementation Approach*

Patagonia has been a pioneer in taking unique measures and being steadfast in its journey towards sustainability of its business model and achieving operational efficiency with bold measures which has helped in winning the loyalty of customers. The company has also leveraged data analytics and artificial intelligence widely in its operations which have helped it in tracking and forecasting global inventories with unmatching efficiency compared to its competitors. Having been a long-term user of IBM business analytics software, Patagonia found the solution to this early-identified problem of managing its inventory model by collaborating with a consulting company named Aviana, a long-time IBM premier business

partner, to streamline its budgeting process using a software tool based on data analytics and AI that helps finance professionals analyse and manage large amounts of financial data. It is a multidimensional database with a spreadsheet-like structure that allows users to create financial models and perform advanced calculations. Using this technology, Patagonia worked towards developing a new analytics application to help them monitor and forecast global inventory in detail. This helped them to attain a faster and more flexible budget solution as well as a more timely and better insight into the forecasted global inventory position.

*Efficient Management Practices for a Resilient Supply Chain and Business Model*

The business leaders and the management executed the implementation of the project in a manner that helped Patagonia to become one of the first companies in the apparel sector to specialize in business analytics and performance management solutions. The first phase of the project focused on re-engineering Patagonia's budgeting process to take advantage of their analytics engine, to increase the performance of very large data models. Through this, they were able to consolidate 25 old budgeting models into four new digitally advanced models while improving the overall performance and flexibility of the development process. It helped them in streamlining the preparatory work required both at the start of the budgeting cycle, and during the consolidations process throughout the budgeting cycle, and creating a more interactive environment during the input phase of the budgeting process and providing better visibility on the budget model.

The second phase of the project involved the development of a new analytics application to complement Patagonia's existing merchandise and supply planning tools and processes by enabling Patagonia to forecast detailed future inventory levels. It used a combination of data from previous periods, current inventory levels, open and planned purchase orders, sales forecasts and other factors to calculate the quantities of each product that each region will have over the next several months. With large amounts of data in the model, the application relied on the performance of the analytics engine to deliver flexible reporting with good performance. This implementation enabled the entire data to be analysed more rapidly via the new digital reporting tools.

*Impacts based on the Decisions and Actions Taken*

This project helped Patagonia's budgeting process improve tremendously by eliminating cumbersome administrative data links and procedures. The new inventory analytics model

helps them to improve merchandising and supply analysis and planning by forecasting future inventory levels. Additionally, it is expected to support them in performing more detailed inventory planning down to the style and colour of products, as well as categorization by the geographic regions. Being a global brand, their inventory data is managed by systems across multiple sales channels including retail stores, wholesale and direct sales across multiple regions, it was difficult to provide timely visibility to their global position at the time, let alone forecast future positions. However, with the new analytical model developed through this project, they are better suited to make better decisions for managing their inventory levels and hence improve their supply chain management and planning to help ensure that the right products are in the right place at the right time. By helping to mitigate the risks of over- or under-stocking, the solution is expected to ultimately assist them in their effort to reduce total inventory costs and avoid the loss of potential sales due to out-of-stock items. Hence, the adoption of the shift to digitally transform immensely helped in streamlining their supply chain and deriving maximum sustainable profits out of the business model.

The most impactful initiative undertaken by Patagonia, which is the innovative introduction of QR Codes, helped discover that switching from paper hang tags to QR codes led to a significant decrease in the variety of tag options from 453 to only 20 variants. This adjustment resulted in a reduction of 170,000 pounds of waste in landfills during one season. The QR codes affixed to each garment offer customers access to product details instead of having multiple printed versions. This modification not only contributed to reducing environmental impact but also lowered expenses linked with creating and handling hang tags. Using QR codes not only helped Patagonia cut down on environmental waste but also made their internal processes much smoother and efficient. Before switching to QR, Patagonia spent around 2,819 hours each year on creating garment hang tags. This digital shift now only requires three days annually showcasing an enhancement in operational effectiveness. Moreover, this transition lightened the workload for the editorial and design teams and thus granted them the freedom to concentrate on strategic projects instead of getting bogged down with manual duties.

*Long-term Planning to tackle the Emerging Trends and Future Challenges*

Patagonia considered the long-term benefits and solutions while implementing the digital transformation projects. It took care of the fact that the solution will also support new analytical reporting on a number of key performance indicators (KPIs), helping Patagonia monitor specific measures such as past and future inventory turns and weeks of supply for specific

regions, products or groups of products. By providing insight into seasonal fluctuations and trends, this new inventory forecast model is also planned and expected to help the company respond more effectively to market conditions, unforeseen events and other external influences. Additionally, Patagonia uses Artificial Intelligence to enhance its visual branding tactics by producing eco-friendly clothing that resonates with its core belief in sustainability principles. Not only does this strategy involve just the physical elements of product development but also extends to crafting a narrative that reflects a commitment to environmental stewardship. AI empowers Patagonia to create items that have less environmental footprint by utilizing sustainable materials that reduce resource usage and pollution. This two-fold emphasis on technology and sustainability awareness boosts Patagonias image as a brand that promotes a sustainable lifestyle and thoughtful consumption. AI technology is also crucial for Patagonias communication with its customers. It uses AI tools to examine customer information in order to grasp their preferences and behaviours. This enables Patagonia to customise content and marketing tactics for each individual. This personalised method not only boosts customer involvement but also nurtures a stronger bond between the customer and the brand. Advertisements driven by AI and product suggestions are designed to make Patagonia's marketing strategies resonate personally with customers reinforcing their loyalty and connection to the brand.

Another significant example of Patagonia's long-term planning is the strategic use of AI towards promoting environmental awareness in branding through its 'Worn Wear' campaign. This initiative utilizes AI to analyse consumer data and accordingly craft a campaign that raises awareness about the environmental impact of the fashion industry. The Worn Wear campaign encourages consumers to participate in clothing reuse and recycling which aligns with Patagonia's commitment to sustainability. The success of the campaign is clear from the rise in engagement rates. For instance, in Europe during 2016 to 2018 there was a 50 percent increase in the amount of clothing repaired or recycled through the Worn Wear program showcasing how AI cannot just boost brand image but also promote sustainable consumer behaviours. Patagonia's utilization of AI showcases a fusion of technology and brand strategy that elevates its visual identity and sustainability initiatives to new heights. Through the use of AI technology, Patagonia effectively conveys its dedication to stewardship proving that branding innovation can coexist with a strong ethical stance. As digital advancements progress Patagonia stands out as a leader in demonstrating how AI can foster a relationship between creativity and sustainability within today's business environment. Patagonia has leveraged digital

technologies to innovate its product packaging and reduce its environmental impact. One notable example is how the company's overhaul of its garment paper hang tag process, helps significantly minimize waste and improves its operational efficiency in the long run.

*Discussion on the Analysis*

a) Patagonia's move towards digital solutions reflects its commitment to operating in an environmentally friendly manner while ensuring effective communication with customers remains a top priority for the company. For instance, by embracing digital solutions instead of traditional hang tags for product information dissemination to customers enables Patagonia to educate about product features and material technologies without the added environmental cost associated with paper usage. This shift towards innovation not only supports Patagonia's overall sustainability objectives but also highlights the positive impact that small changes can make on both the environment and business practices. Utilizing digital technologies has led to significant enhancements in their supply chain management and operational efficiency. The company has improved its capacity to meet market needs and promote sustainability objectives through the combination of e-commerce platforms, with data analytics and supply chain tools.

b) Encouraging Industry-Wide Adoption: Patagonia openly encourages other retailers to incorporate similar digital solutions in order to cut down on single use materials and enhance both environmental and financial results alike. Their method serves as a prime example of how using digital technology effectively can bring about substantial sustainability benefits like reduced waste production and increased operational effectiveness.

c) Sustainability Achievements: Patagonia's commitment to environmental, social, and governance criteria has strengthened its brand reputation and market position. The company's achievements in reducing its carbon footprint, using sustainable materials, and maintaining fair labour practices are its key drivers for success**.** Digital transformation and strong ESG practices have provided Patagonia with a competitive edge, allowing it to lead in both market performance and sustainability.

d) Implement Circular Economy Practices in conjunction with digital technologies: Projects like Worn Wear and the Recycled Materials Initiative which were already being driven by Patagonia gained more audience and became more widespread when combined with the

utilization of digital technologies by highlighting the importance of extending the product lifecycle and reducing waste to a wider population.

Patagonia's success in embracing digital advancements and sustainability emphasizes the significance of merging digital technology with ESG values in corporate strategies. The brands effective utilization of resources and dedication to environmental and social ethics have established a notable standard in the consumer goods industry. This real-world example highlights how creativity and moral values play crucial roles in attaining operational efficiency and enduring sustainability.

### 4.4 Illustrative Example 4: Walmart vs Toys "R" Us Digital Transformation and Sustainability Journey

All the three case studies done so far were focused on analysing the digitally driven sustainability efforts of three multinational organizations and how they continue to stay relevant and in the leading positions in their industries. This case study has been investigated from a different perspective by comparing Walmart for its successful implementation of efficient supply chain, to Toys "R" Us, for how it failed to incorporate digital solutions which eventually led to its failure. In detail, it investigates how the advancements in digital technologies are affecting supply chain management and the endurance of business models within the retail sector by looking at Walmart's effective use of digital transformation to improve its operations and sustainability compared to the inability of Toys "R" Us to adjust to digital shifts. The findings aim to highlight the critical role of technology in achieving economic, environmental, social, and governance (ESG) objectives. Since Walmart operates on a wide range of products apart from the products handled by Toys "R" Us, the analysis has been done by contrasting the supply chain of specific product divisions within both the companies to compare them from a similar scale.

The retail industry involves selling goods and services directly to consumers, including various sectors like groceries, electronics, clothing, and toys. Walmart, which was founded in 1962, is a leading global retailer with a diverse range of products which include groceries, apparel, electronics, and more. It operates extensive physical stores and a robust e-commerce platform. Walmart has been a leading organization in the retail sector, with its business model always

focused on cost leadership, operational efficiency, and an integrated online-offline sales strategy. Toys " R " Us, established in 1948, was a leading toy retailer renowned for its selection of toys and children's products available in its physical stores. Operating within the sector, Toys " R " Us focused on offering toys, games and children's products, like baby essentials, educational toys and games. This niche within retail was specifically dedicated to providing products for children and families. Its model was solely cantered around physical stores, with limited investment in e-commerce and digital tools.

*Impact of Trigger Factors and the Need Identification for Digitalization*

The key aspects and shifts in the nature of the retail sector involving toys and juvenile products served as the main catalysts behind Walmart's need to immediately focus on digital adaptations in its supply chain. Both the organizations dealt with the sales of a detailed range of products including toys, games, puzzles, educational products designed for various age groups, and juvenile products such as baby gear, clothing and accessories. The target population mainly included families with children, and hence the products catered to the taste of both parents and kids. In the past, the only mode of distribution and supply chain was traditional, through the physical stores but with the onset of digital technologies, the trend started shifting towards online retail on a large scale. It became essential to expand the presence with e-commerce platforms, alongside the physical stores. The sector started changing completely as e-commerce began growing exponentially and altered the way customers behaved and interacted with the organizations. All these events were rightly identified by Walmart which began the digital shift and the gradual transformation of its traditional supply chain into digital. Toys "R" Us, which was a category killer and a leading giant in the sector lacked the ability to recognize the importance of the shift.

*Proactive vs Delayed Decision-Making and Implementation Approach*

Walmart was proactive in its digital shift and began adjusting to the digital movement early on while Toys "R" Us failed to realize the importance of this. Hence, Toys "R" Us lacked the competence to keep up with the competition of Walmart and other companies that began incorporating online platforms alongside advanced analytics and streamlined logistics processes. As a result, Walmart succeeded in beating and replacing Toys "R" Us for the title of the top toy seller in the United States. This downfall of Toys "R" Us occurred thanks to its well delayed identification approach. Over the years, Walmart started continuously investing in

emerging technologies and became well-known for being a company that continuously innovates and is always at the forefront of digitalization. Its digital journey started by integrating physical and digital retail and implemented several initiatives to take advantage of the gap left by Toys “R” Us. During the time when many US retailers were working to bolster their toy ranges to fill the gap brought on by the unfortunate delayed approach of Toys “R” Us, Walmart ensured that it was at the leading edge where they tried to fill the gap by introducing a ‘National Play Day’ in 1,500 of their store locations allowing kids to play with the most popular toys of 2018. In conjunction with this launch, Walmart created a digital ‘Toy Lab’ on their website allowing kids to see those same toys online and engage with new content on these toys. The kids in the store were prompted to save their favourite toys into a digital ‘Toy Box’, similar to a wish-list in the online shopping websites, which they could send to parents and grandparents. This Toy lab with its Toy Box functionality was introduced in stores, where employees helped the families, despite also being made available to everyone online. This assured that Walmart continued to grow even in a retail environment dominated by Amazon, presenting a huge turnaround and exploiting the opportunity presented by Toys “R” Us’s gap and its eventual collapse. Walmart acted at the right time with the right approach by recognizing which value driven experiences could be delivered in store and how they could be delivered by translating it into the digital context so it can be amplified in the future.

The industry was facing multiple challenges, of which the major ones were factors that had the potential to cause huge losses and inefficiencies in the supply chain of the companies that did not find efficient digital solutions. The major challenges included the misplacing of items on the wrong shelf, refilling of the stock based on the inventories and stock-out rates, danger-proofing against wet surfaces at the storage units and retail stores, efforts spent in repetitive tasks such as cleaning/scrubbing the floor and shelves. To fight against all these challenges, Walmart took an informed decisional approach to exploit Artificial Intelligence for stock management and store cleanliness. It developed an AI lab in its stores to monitor misplaced items and detect low-stock items using cameras. They partnered with Bossa Nova to use AI robots to maintain store shelves. Walmart provided sponsorship to the Texas A&M University for computer vision projects, including creating camera systems to detect floor water and partnering with Brain Corporation to make floor-scrubbing robots that use sensors to navigate and clean.

While Walmart took several technology driven initiatives to address the challenges, Toys “R” Us followed a passive strategy that involved a delayed e-commerce integration and poor online network presence and hence less accessibility, visibility and efficiency. They were not quick to adapt to the rise of online shopping that transformed the retail industry landscape. Companies such as Walmart and Amazon swiftly grew their storefronts and provided customers with a smooth online shopping experience, whereas Toys "R" Us failed to give sufficient attention to enhancing their e-commerce capabilities until it was too far into the game. When they finally decided to invest into their online platform, they had already surrendered a significant portion of their market share to the agile competitors such as Walmart. When Toys "R" Us finally tried to establish a presence, the connection between their physical stores and the digital platform fell short of the then expectations. Their online shopping experience received feedback for being difficult to navigate and lacking the advanced features seen on contemporary e-commerce websites. This disparity in customer experience across offline channels hindered their competitive edge.

*Laggard vs Efficient Management Practices affecting Supply Chain and Business Model*

The management approach taken by both the companies led to the success and downfall of each in the long run. Toys “R” Us lagged in adopting digital approaches despite the many indicators and trigger factors happening right in front of them in the industry. Even after the issue was recognized, the management failed to cover up and quicken the pace of change by taking a few wrong decisions without long-term thinking. Toys "R" Us initially partnered with Amazon to handle their online sales, which, although a strategic move at the time, limited their control over the digital customer experience. When they eventually launched their own e-commerce site, it was already too late, and they faced challenges in building a competitive digital presence and integrating their supply chain with their new online strategy. Another contributing factor to their collapse was their inability to innovate and adapt to changing consumer preferences. While other retailers were leveraging digital tools for personalized marketing, data analytics, and improved inventory management, Toys "R" Us was slow to adopt these technologies.

Contrary to the slow approach taken by Toys “R” Us, when presented with the industry challenges, Walmart’s management practices not only helped it to quickly adapt digitally but also go way beyond what was considered as a necessary digital change at the time. For instance, the industry of toys and juvenile products often faces challenges when it comes to providing a

unique customer experience, since it caters mainly to kids and adults alike based on their preferences and the customers to whom this industry mainly caters to can tend to lose their attention in a very short span. Hence, it faces a few unique challenges which are not easily solvable, such as the infeasibility of facilitating a one-go comparison of different products based on prices, ratings etc. It was difficult to find solutions to make the retailers create engaging and fun experiences for enhancing the customer shopping experience. Walmart rightly identified that the key to solving such challenges would be to capture the attention of the customers and make their experience interesting. They used Virtual Reality to train their associates by providing them with a simulated store environment to learn and handle real-life situations. Walmart acquired a VR start-up named Spatialand to create VR software for its stores. Similarly, when faced with the challenge of shifting to a customer-oriented optional combination of in-store, pick-up and delivery of products to increase the convenience and comfort factor, Walmart partnered with Ford to test using self-driving vehicles for product delivery, gathering data on consumer preferences. Additionally, when a majority of the competitors, both existing giant players and the new entrants had not even integrated into the basic digitization trends, Walmart successfully took advantage of the situation by going an extra mile in solving the challenges of managing data on thousands of proprietary servers is a challenge for retailers who rent computing capacity to serve their customers effectively. Walmart entered a five-year agreement with Microsoft in mid-2018 to use the Azure cloud platform and convert all websites and apps to run natively on Azure. This helped improve Walmart's ability to store and analyse data to drive online sales and enhance its supply chain profitability and business model sustainability.

*Impacts based on the Decisions and Actions Taken*

Toys "R" Us made a pivotal decision to go from public to private in a six billion dollar leveraged buyout deal. The plan for this buyout was to boost sales and increase stock offerings so investors could cash out. However, this did not work out and the company attempted to go public again, but later withdrew due to declining sales. They brought in a change of management by introducing four new CEOs in sixteen years to try to help the struggling company. As a result of the collective effect of all the actions taken by its management and the business model practices which did not help it overcome the challenges on time and a huge competitive landscape, the company finally announced its bankruptcy in 2017.

*Long-term Planning to tackle the Emerging Trends and Future Challenges*

Toy consumption is a global contributor for ongoing issues about environmental justice and climate change. Each year, approximately sixty million Barbie dolls are sold, contributing emissions equivalent to burning 381 million gallons of gasoline. Production and packaging consumed 40 tonnes of plastic for every $1 million in an average toy company revenue. Toys make up six percent of all landfill plastics. Beyond the wall of indifference, manufacturers and consumers can lower these numbers using the tools of design, material selection, and marketing. Walmart, being the largest retail company globally, has incorporated this into its long-term planning and made a commitment to adopt sustainable packaging through digital technologies. To achieve this goal, the company has launched an online platform called Circular Connector. The purpose of this platform is to promote innovation in sustainable packaging by connecting suppliers with brands looking for sustainable solutions. The platform allows suppliers to submit their sustainable packaging innovations for review and potential publication online, providing companies with a wide range of sustainable packaging options to consider, thereby giving an opportunity for continuously gathering information and improving its supply chain practices.

*Discussion on the Analysis*

The comparison case study analysis of Walmart vs Toys “R” Us helped the research in identifying the factors that lead to a leap in one company’s success and emergence as one of the topmost business leaders in the retail business, and the events that led to the decline of another company, thanks to the approaches adopted towards digital transformation in retail. Toys "R" Us' difficulties with digital transformation illustrate the risks of falling behind in the rapidly evolving retail landscape and the need for retailers to continuously adapt to technological advancements and consumer expectations. It is significant to note the circumstances and stimuli that led to these outcomes so that the companies can avoid committing such failures in the future by identifying patterns and key lessons. The table 4.2 summarizes the strategies adopted by each company that led to their success and failure respectively.

Table 3. Comparison of the Successful & Failed Strategies adopted by Walmart & Toys R Us

| **Walmart** | **Toys “R” Us** |
|---|---|
| ***Early Adoption and Digital Integration***: Walmart's success was caused due to its | ***Delayed digital integration***: They failed to create a strong online presence in the form of |

| | |
|---|---|
| efficient timed initiatives of introducing seamless integration of online and offline channels includes features such as online ordering, in-store pickup, and home delivery, and the integration of online and offline channels, huge investment in technology, and efficient supply chain management. | an e-commerce site and to integrate the internet with the brick-and-mortar stores. Many customers complained that the company's online store was unattractive and not very convenient to use compared to other popular e-commerce platforms. |
| ***Continuous Innovation and Supply Chain Adaptation***: Walmart took advantage of the technologies to utilize data analytics for demand forecasting, inventory management, and personalized customer experiences. AI technologies enhance operational efficiency and customer engagement. | ***Inefficient Supply Chain Management and Strategic Error-based Business Model***: Toys "R" Us miscalculated its strategy, including an initial dependence on outdated and inadequate supply chain models and later depended on Amazon for its online sales. Although the partnership was intended to boost its e-commerce presence, it limited Toys "R" Us's control over the digital customer experience. When the company attempted to build its own e-commerce platform, it struggled to compete effectively against established players. |
| ***Unrelenting Digital Adaptations:*** Walmart utilized digital technology to streamline its logistics and reduce costs by employing automated warehouses and real-time inventory systems. | ***Insufficient Technology Investments:*** Lack of focus on adopting modern supply chain technologies and digital resources led to inefficiencies in operations for Toys "R" Us. This lack of investment restrained the company from optimizing its supply chain efficiency and enhancing the overall online shopping experience offered to customers. |

Source*: Personal elaboration of author*

### 4.5 Analysis and Insights of the Findings

The analysis of the illustrative examples produced insights which could be grouped into common themes, which help in reflecting a better comparative understanding across different stages of the approaches used, which are:

1. *Influence of Events and Factors for Digital Transformation*
2. *Decision-Making Processes and Initial Execution Strategies*
3. *Impacts and Consequences of Actions Taken*
4. *Management Strategies enhancing Supply Chain Optimization and Business Model Resilience*
5. *Future-Oriented Planning for Emerging Trends and Challenges in Digital Adoption*
6. *Strategic Insights and Best Practices to Adopt*

*Stage 1: Influence of Events and Factors for Digital Transformation*

The first stage that was determined as being common across all the case studies involved the identification of key internal and external factors identified by the companies that slowed down their existing supply chain management practices and business models. This stage also included the recognition of the urgent need to advance towards a digitalization move to keep up with the technological advancements, customer expectations, and competitive pressures. The insights from the research outcomes of the companies revealed that the global events that led the companies to shift their traditional supply chain approaches were similar and occurred approximately during the same timeline when Industry 4.0 came into picture. The primary shift in focus and concern towards the incorporation of sustainability into the initiatives also started rising profoundly during this time for all the companies. Hence, digitalization was causing huge disruptions in the supply chains and the companies that started adopting digital solutions were a huge threat to those who were not ready to adapt. All the organizations were thereby forced to readapt their supply chain strategies from the sourcing stage till the stage of allocating products to the end-customers. For achieving this, it was necessary to redesign the entire business model to digitalize and automate every possible area of operation and thus cause a significant impact on the stakeholder ecosystem with efficient solutions catering to not just operational efficiency but also in the areas of environmental, social, economic and governance aspects. However, these shifts were not just a challenge in a pessimistic way to the companies, but they served as an opportunity to race ahead and rise to beat even the leading giant

companies within industries, such as how Walmart beat slowly adapting retail companies such as Toys “R” Us who was once the leader in the sector. Exploiting these digital technologies helped the companies in more outreach towards both suppliers and consumers due to the availability of multiple media and channels.

In the case of companies such as Unilever and GE, which operate across multiple product lines and supply chains, the immediate challenge was regarding the risk mitigation of all the processes and performance metrics that were causing inefficiencies. This was rightly identified by them as opportunities that could be solved through digital transformation. They leveraged technology by implementing digital solutions in addressing the challenges of redesigning the increased costs and delivery times in all the stages of their supply chains across the world. This preparation was also necessary to be ready for facing and recovering quickly from unexpected global and regional scenarios, including both natural events and unpredictable political or economic events which could otherwise have caused potentially irrecoverable damage.

This section emphasizes that the challenges outlined through the literature review analysis and the existing theoretical framework of this thesis resonate with the perspectives obtained through the individual detailed studies of industry experts of Unilever, General Electric, and Patagonia regarding digitalization for better supply chain and business model management. The insights revealed that not adopting digital methods, and especially not changing the mindset to adapt digitally, is regarded as a significant threat to the continued survival of the companies despite being leaders in their industries. This difficulty to adapt for some companies might have arisen likely due to the thinking that the potential of digitalization to revolutionalize the supply chains and business model practices was negligible. For instance, Toys “R” Us failed to recognize the importance and the criticality of technological adaptation as a pressing issue, which eventually led to its bankruptcy.

*Stage 2: Decision-Making Processes and Initial Execution Strategies*

This stage focuses on the companies’ decision-making approaches and strategies based on the decisions for addressing the needs identified for digitalization of their operations. Among the various approaches presented in the case studies, three approaches were identified as common among all the companies that led towards their success and ability to stay relevant in the industry. It also highlights the lack of implementation of these approaches by Toys “R” Us, the company that failed in the journey. One of the primary approaches which emerged as the

common ones used by all the companies was the prioritization of digital initiatives based on their impacts and feasibilities applied to the industry contexts through the utilization of data to take informed decisions. The data-driven decisions were used to apply to the supply chain management practices and were used to develop tools and projects such as the SAP HANA Project introduced and implemented by Unilever for the optimization of its supply chain management. GE also utilized data analytics to use it for the implementation of supply chain processes managed and automated by technology to reduce the inefficiencies in the efforts, costs and downtimes across its varied range of businesses including aviation, power and healthcare. Hence, data analytics tools were particularly useful for all the companies in identifying critical issues and bottlenecks in their business models and helped report the stage-level processes in an interconnected manner to all the stakeholders, thereby increasing the transparency as well.

This brings the focus point to the second major approach adopted by the companies in common, namely, the stakeholder engagement. The initiatives to optimize the supply chains helped the companies in involving all the key stakeholders in the entire decision-making processes to ensure the alignment and buy-in at every stage of the process. This is especially true in the case of Patagonia, which ensured the above average treatment and commitment towards all its stakeholders through its sustainability initiatives which additionally helped in its business model efficiencies. This aligns with the research presented through the theoretical concepts in the first two chapters that the incorporation of digital technologies in either the supply chain or the business model serves as an interrelationship among all the three elements, simultaneously enhancing all the three individually as well as the correlation among them. The third mutual approach identified was the usage of a phased implementation approach, where the companies were observed to adopt an iterative approach to implementations of their decisions and actions, allowing for adjustments based on the feedback and performance metrics from the data. For example, Walmart incorporated multiple technologies and made them work together and ensured that they did not work in silos to maximize the potential benefits. The same approach helped GE in developing Digital Twins using scenario simulations and real-time mapping tools, mixing digital and physical real-world models.

*Stage 3: Impacts and Consequences of Actions Taken*

This stage discusses the most common impacts that the companies were presented with through the effect of implementation of their decisions and corresponding actions. These included the improvement of the operational efficiencies of the supply chains in terms of enhanced productivity and efficiency as a result of their digital initiatives. These supply chain efficiencies finally helped the companies in their financial performance, through the increased impact on revenue growth, cost reduction and overall productivity. Apart from this, the other major perceived impact that the companies derived through digitalization was the increased customer satisfaction. They were able to assess how digitalization helped enhance the customer experience and engagement. For example, with the help of the SAP platform that helped in advanced planning and optimization, Unilever was able to optimize its production planning and scheduling thereby enabling an additional capacity for daily sales orders at 6.8% more than the previous capacity. This operational efficiency indirectly positioned Unilever to a potential revenue increase of €125 million and an additional margin of around €50 million. This proved to be a beneficial cyclic change of events as the project brought changes to Unilever's operations through better decision-making capabilities regarding the right mapping of demand and supply. Apart from the operational efficiency, Unilever also benefitted greatly from the USLP program which helped in a 75% reduction of CO2 emissions within a decade, thanks to efficient technologies such as AI powered systems monitoring energy usage in real time. This has helped Unilever in enhancing its business operations overall.

In this stage, there was a slight difficulty in mapping the decisions and approaches adopted by the companies to the corresponding impacts due to the insufficient and sometimes incompatible availability of data. This is highlighted in the section that explains the limitations of the scope of the study later in the chapter. Due to the same reason, the impacts presented might indicate a slight discrepancy between the theoretical conceptual frameworks presented and the impacts based on the decisions and management practices used by the companies to tackle the digitalization journey. This is due to the availability of data mostly about projects with no direct impacts about their implementations and the availability of impacts of which the projects have minimal data available on their objectives and method and technology used for the implementation.

*Stage 4: Management Strategies enhancing Supply Chain Optimization and Business Model Resilience*

This section examines the patterns in the management strategies among the companies that led to an optimization in their supply chain operations and business models. The common identified management practices among the successful companies that contributed to achieving resilience in their supply chains include accounting for agility and flexibility in the business models. These factors aided in promoting rapid response to the changes in the unpredictable demand and supply conditions. For example, Walmart automated a majority of its in-store and online store processes using technology which helped in achieving agility through real-time visibility among all the stakeholders. It also helped them in achieving flexibility through diversification of routes and suppliers and attain the ability to respond quickly to disruptions. This brings the focus to the second common trait observed in the companies' management approaches, namely, collaboration and transparency which was achieved by encouraging open communication and collaboration across the supply chain to enhance resilience. For instance, Patagonia implemented practices that promoted the support of ongoing evaluation and improvement of processes and technologies through digital solutions. This helped them in attaining an environment and culture of continuous improvement.

In this context, it is significant to note that Toys "R" Us failed due to its management's failure to adopt these elements through digital technologies into their business models. They failed to realize the importance of incorporating real-time visibility into their supply chain and the advantages it brought along for companies such as Walmart, including a rapid and effective forecasting, monitoring and mitigating of disruptive factors. It also failed to realize the significance of having a digitally data-driven solution such as Walmart for gaining critical insights into the physical and capacity management of its stores. This section highlights a highly noteworthy lesson learned through the analysis of the case studies, which is not presented in the literature reviews. The lesson found through the analysis is the huge importance of real-time visibility across the value chain implementable through advanced technologies and monitored through data analytics-based tools. The theoretical research explored the technologies and their applications in terms of improving the visibility of the companies but not specifically their supply chains across the stakeholders. This could be due to the limitations in the usage of technologies for this purpose and the associated costs and efforts.

*Stage 5: Future-Oriented Planning for Emerging Trends and Challenges in Digital Adoption*

The next section identified is the pattern reflected among the companies in their long-term planning approach. The practices adopted account for tackling the unpredictability and impermanence of digital solutions of today, and hence leaving room for adjustments as per the emerging trends and challenges in digital technology solutions. Companies including GE have in place the Digital Twins which have digitally driven tools and data collection methods to regularly perform a trend analysis. They regularly analyse the emerging trends in AI, sustainability and regulatory changes to understand the potential impact on their business operations. The use of Digital Twins also helps them in developing multiple scenarios real-time about the present and the future to prepare well ahead for various future possibilities and challenges. Similarly, Patagonia implemented a digital project that involved the development of an analytics application to complement their existing merchandise and supply planning tools and processes. This enabled Patagonia to forecast detailed future inventory levels much before the time. Hence, these companies implemented solutions using technology not only to compete with their direct and indirect external competitors but also within themselves to their previous performances. This helped them in utilizing digital methods to improve their business models at a never-ending incessant pace.

Another significant factor that contributed to the successes of the companies was the right identification done by them in choosing which digital technology to implement, at what stage of the business, and most importantly, whom to partner with. Observing the findings from the case studies of the companies helps in identifying that the successful companies performed this step rightly. For example, Patagonia partnered with IBM, Unilever with SAP and GE with AWS at the right time only for the right areas in which they required support for their supply chains and business models with digital implementations. Similarly, Walmart also got into many partnerships with different firms for their digital advancements. However, Toys “R” Us which also underwent the management approach of partnership did it the wrong way and at a wrong time in their journey. They partnered with the retail giant Amazon for managing their operations hoping to control the operations by themselves at a later stage. However, they failed to realize the strength and reach that this gave to Amazon which was already a direct competitor to Toys “R” Us and operating at a much larger scale. These examples and insights reveal the decisive role that this factor plays in the ability to manage unforeseen factors and trends efficiently.

*Stage 6: Strategic Insights and Best Practices to Adopt*

The last section which is the last stage of the analysis explains the common identified factors that helped the companies in adapting their strategies from a traditional approach to a modern one. These include the following:

a) An unparalleled investment in digital technologies: It should not be confused with investments in any technology with no planning or estimation of the costs and maintenance efforts involved. The right strategy to adopt is the prioritization of investments in digital tools and platforms that align with the strategic goals of the companies and the industrial scope in which they operate. Companies such as GE and Walmart continue to stay successful due to their incorporation and cultivation of a digital mindset in their operating and work culture and encouraging a culture of innovation and adaptability within the organization. The case study comparison of Walmart vs Toys “R” Us highlighted the crucial role of digital transformation and ESG adherence in shaping the success or failure of retail companies. Walmart’s strategic investments in technology and sustainability positioned them a leader in the retail industry, while Toys "R" Us’s inability to adapt to digital trends and address ESG concerns led to its downfall. This inculcates the importance of digital innovation and adhering to ESG principles for long-term business success and sustainability. Toys "R" Us’s downfall serves as a cautionary tale for other retailers while laying emphasis on the importance of embracing digital transformation comprehensively and aligning the company’s strategies with ever evolving consumer expectations to avoid similar hurdles.

b) Benchmarking and Adopting Proactive Management Practices: Another management practice that proved highly beneficial which can be adopted as a strategic recommendation for the emerging companies and the companies aiming to emulate the leading companies is to learn from the industry leaders. At every stage of implementation, it is very essential to plan, prioritize and implement best practices to guide the digital transformation efforts through a comparison of what the industry leaders, peer companies and even the companies operating in other similar sectors have done in the past and the present. Looking at successful companies like Unilever, it is observed that even if they have had setbacks at some stages, they still continued to rise and thrive among the leading companies because of their ability to perform benchmarking with others through digital tools using data analytics and finding best digitally driven solutions through the exploitation of these data and technologies.

c) Continuous Learning using Emerging technologies to enhance sustainability: The companies should promote ongoing training and development to ensure that their teams are equipped

enough to leverage new technologies effectively. There should be a high focus on innovation by prioritizing investment in innovation to stay ahead of industry trends and competition. As learnt through the case studies, this helps the companies in the diversification of transportation routes and the ability to respond quickly to disruptions which will serve as critical components of resilience. Companies that invest in these areas are better prepared to face potential challenges and maintain operational continuity. Digital technologies, such as AI, help us identify at-risk shipments through data analysis for Unilever and GE. They help in finding areas to reduce the maintenance and operational costs and avoid obstacles and hence improve the warehouse efficiency. However, it is important to highlight that there is a significant discrepancy between the application of these innovations in the theoretical frameworks and their actual use in the business operational reality.

d) Acknowledge and plan long-term for the digital technology integration challenges: One of the primary challenges that companies should account for, form a full-fledged plan and prioritize are the integration challenges to form a synergy among digital technologies, supply chains and business model to ensure the long-term sustainability. Despite their potential, a few digital technologies such as Digital Twins of GE face challenges such as high deployment costs, integration with existing systems, and the need for robust data security. These barriers can slow adoption rates but are critical to address for realizing the full benefits of Digital Twins. Hence, companies should plan efficiently to accommodate these costs at an early stage, by investing in efficient technologies wherever they can save costs.

e) Use a strategy of Technological Synergy: As highlighted in the study, advances in AI, IoT, and cloud computing have provided the foundation for the rapid evolution of digital innovation. These technologies work together to enable more accurate simulations, real-time analytics, and improved operational insights. The integration of supply chain and business models with digital technologies allows for advanced simulations and analysis when combined with other digital tools. Companies such as GE and Walmart that applied this digital synergy had better opportunities in improving their decision-making processes which led to better system designs. This capability helped them to work proactively and address complex challenges at an early stage and prevent costly redesigns.

## CONCLUSIONS

This thesis has conducted a comprehensive analysis of the role of digital technologies in supply chain management and business model sustainability. It highlights the risks posed for the long-term survival of supply chains, emphasizing their potential lack of relevance if they do not perform regular digital upgradation. As highlighted in the analysis, lack of digital capabilities and mismanagement in adopted digital strategies can put the supply chain resilience and business operations of companies at a huge risk. These were examined through theoretical research and real-world examples of companies based on the available sources. The key factors that triggered the identification of the urgent need for digital acceleration of business strategies were examined in detail. Rising consumer expectations regarding personalization and improved services, competitive pressure, leveraging advanced tools for smarter decision-making and reducing operational inefficiencies were indisputably the fundamental turning points. As observed, global shifts and complexities in maintaining global supply chains also necessitated the companies to reassess and transform their business models and supply chain strategies to remain resilient. Companies that rightly recognized the significance of this need adopted a proactive approach integrating digital solutions to their strategies. Once the right approaches were identified, the companies were faced with the immediate need of decision-making and proactive implementation to reap maximum benefits. This had to be done after exploring the possibilities of achieving digital synergies to utilize and integrate data from all possible sources, together with methodologies for visualizing the data and the outcomes. In this stage, it was necessary for the companies to understand their operations and the industry scope in depth before jumping to miscalculated conclusions.

Based on the decisions taken, the companies identified the importance of achieving a balanced interrelationship among digital technologies, supply chain and business model mapping to attain sustainability, which is the central element of this thesis. Management practices incorporated strategies to tackle both immediate and long-term challenges as per the emerging global trends to be able to respond quickly to unforeseen events. These strategies included identifying the right partners and importantly, the right way to form partnerships to find advanced digital solutions to deal with the unpredictable nature of the business environment and the pace of digital evolution. Hence, companies focused their efforts on the diversification of supply sources, the adoption of flexible contracts and the reengineering of the supply chains to create agility in the business structures. These helped them achieve high operational efficiency, error reduction and quality management. This aided in attaining the goal of creating

a synergy among the technologies, supply chain and business models to achieve the best combination of sustainability in the economic, environmental and social verticals. Innovations through this synergy helped in creating sustainable operations as they improved system efficiency and resource management. As examined through the case analyses, mastering this interrelationship in complex industries such as GE's energy and aviation supports the development of sustainable practices. Hence, while challenges remain, the evolution and integration of technologies promised significant advancements in efficiency and sustainability across various sectors.

The insights presented in this thesis are highly relevant for the emerging and leading companies. It includes a thorough review of the theoretical literature, complemented by an analysis of case studies of companies as real-world examples. While the literature outlines the characteristics and potential advantages of technologies and their implementation in supply chains, the practical examples often temper the perceived benefits of these applications. Key challenges, such as insufficient foundational knowledge, efforts and costs involved, hinder their effective implementation. However, it should be noted that companies are making investments to integrate these technologies into their existing monitoring and control systems considering the long term. Overall, this thesis provides a comprehensive set of best practices for industry professionals looking to enhance their management and control capabilities within their supply chains, addressing critical factors that are often overlooked or insufficiently explored in the current academic landscape.

In this context, it is significant to mention the major limitations encountered in the research, due to its qualitative nature and the insufficient data availability on the disruptive effects of digital technologies on the companies. Additionally, the unpredictable nature of regional and global economic and political scenarios and cultural backgrounds might have the potential to influence the generalizability of the proposed strategic recommendations. Since the thesis is based on secondary research which often relies on correlational data, the lack of opportunities to do primary data collection contributed to the inability to establish clear cause-and-effect relationships wherever any associations are indicated.

These limitations do not hinder the adoption of the recommendations in the thesis as several techniques were applied to address them. Multiple secondary data sources were integrated and cross verified from different sources to create a comprehensive view, incorporating recent publications and diverse geographic contexts to mitigate the impact of generalized and outdated

data and enhance the relevance to the research objectives. To address the challenge of establishing causality, the analysis involved a personal-like involvement with companies to provide in-depth insights and infer potential causal relationships. Companies and cases were chosen from multiple industries for a 360 degree analysis to ensure that the thesis reflects a balanced representation of positive and negative outcomes. This approach aided in providing a richer, more nuanced understanding of causality beyond what was otherwise possible with secondary data alone. Acknowledging these limitations in advance allowed the research to thoroughly evaluate the pros and cons of the research areas while remaining mindful of biases to bolster the overall credibility of the findings. Hence, despite these limitations, the thesis is a valuable tool for understanding and managing the challenges imposed by events that increasingly characterize the business environment. In short, the research gap in the literature review, regarding the integration of technologies in supply chain to increase the resilience of business models against disruptions, is filled.

Additionally, this research paper seeks to encourage and guide future research and practical developments. It recommends further investigation into the current use of technologies by companies, their effectiveness in enhancing supply chain optimization, and their influence on business model sustainability. Businesses looking to deepen their understanding of this topic are encouraged to first evaluate their own supply chain operational environment and business model structure, which can be challenging. To assist with this, the study offers best practices and a comprehensive overview of trigger events, tailored to the context of digitalization in this age. Companies should examine their foundational technology capabilities, especially in data analytics and synergies, and the availability of skilled personnel. While the technologies promise enhanced sustainability of business models, they require substantial financial and infrastructural investments. Consequently, this study serves as an invitation for those interested to reflect on their status quo and align it to their short and long-term objectives.

In conclusion, it is important to understand how these findings and results will practically impact or help businesses and sustainability of their supply chains. The findings highlight the transformative potential of technologies across various industries. A company’s ability to seamlessly integrate physical and virtual systems will offer substantial benefits for businesses, supply chains, and sustainable business models. Supply chain management through digital technologies is central to companies' operations, especially in an international context of increasing uncertainty. At the same time, the ever-evolving technological trends offer

possibilities and management horizons that were unthinkable a few years ago. Precisely because of this, the integration of these innovations, together with management and organizational best practices, will be the future drivers of the business model designs, significantly improving the ability to respond to increasingly numerous and unpredictable crises. By addressing these key areas, organizations can enhance their resilience, adapt to changing market conditions, and position themselves for long-term success in an increasingly digital landscape.

**BIBLIOGRAPHY**


- Albanese, J. (2017, November 9). *The Death of a Toy Retailer: How a Lack of Digital Transformation Helped Destroy Toys "R" Us*. Inc.Com. https://www.inc.com/jason-albanese/the-death-of-a-toy-retailer-how-a-lack-of-digital-transformation-helped-destroy-toys-r-us.html
- Altiok, T. and Ranjan, R. (1995*). Multi-stage, pull-type production/inventory systems. IIE Transactions, Vol. 27, pp. 190-200. Angeles, R. (2005). RFID technologies: supply-chain applications a*
- Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787-2805.
- Bag, S., Telukdarie, A., Pretorius, J.H.C. and Gupta, S. (2018*). Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmarking: An International Journal, 28(5). doi:https://doi.org/10.1108/bij-03-2018-0056.*
- Baker, P., & Halim, Z. (2007). An exploration of warehouse automation implementations: cost, service and flexibility issues. *Supply Chain Management: An International Journal*.
- Ballou, R. H. (2006). Revenue estimation for logistics customer service offerings. *The International Journal of Logistics Management*.
- Ballou, R. H. (2007). The evolution and future of logistics and supply chain management. *European business review*.
- Ballou, R. H. (2007). The evolution and future of logistics and supply chain management. *European business review*.
- Baumgartner, R. J., & Ebner, D. (2010). Corporate sustainability strategies: Sustainability profiles and maturity levels. *Sustainable Development, 18*(2), 76-89.
- Beamon, B. M. (1999). Measuring supply chain performance. *International journal of operations & production management*.
- Beamon, B. M. (1999). Measuring supply chain performance. *International journal of operations & production management*.
- Beamon, B. M. (1999). *Measuring supply chain performance. International journal of operations & production management.*

- Bear, S., Rahman, N., & Post, C. (2010). The impact of board diversity and gender composition on corporate social responsibility and firm reputation. *Journal of Business Ethics, 97*(2), 207-221.
- Bechet, M., Siestrup, T., Uhl, A., & Hulshof, H.-J. (2014). Unilever Case Study: Implementing the Real-Time, Digital Enterprise to Unlock Value and Enable Business Growth. *360° - the Business Transformation Journal*, 66.
- Beier, G., Kiefer, J., & Knopf, J. (2020). Potentials of big data for corporate environmental management: A case study from the German automotive industry. *Journal of Industrial Ecology.* doi:10.1111/jiec.13062
- Ben-Daya, M., Hassini, E., & Bahroun, Z. (2017). Internet of things and supply chain management: A literature review. *International Journal of Production Research, 55*(15), 4018-4042.
- Ben-Daya, M., Hassini, E., & Bahroun, Z. (2017). Internet of things and supply chain management: A literature review. *International Journal of Production Research, 55*(15), 4018-4042.
- Ben-Daya, M., Hassini, E., & Bahroun, Z. (2017). Internet of Things and supply chain management: A literature review. International Journal of Production Research, 55(15), 4018-4042.
- Bertot, J. C., Jaeger, P. T., & Grimes, J. M. (2010). Using ICTs to create a culture of transparency: E-government and social media as openness and anti-corruption tools for societies. Government Information Quarterly, 27(3), 264-271.
- Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production, 65, 42-56. https://doi.org/10.1016/j.jclepro.2013.11.039
- Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. Journal of Cleaner Production, 45, 9-19. https://doi.org/10.1016/j.jclepro.2012.07.007
- Bowersox, D. J. and David C. C. (1996), Logistical Management: The Integrated Supply Chain Process. *McGraw-Hill Series in Marketing*, New York: The McGraw-Hill Companies.
- Bowersox, D.J., Closs, D.J., and Cooper, M.B., 2002. Supply chain logistics management. *New York:McGraw-Hill.*

- Bowman, P., Ng, J., Harrison, M., Lopez, T. S., & Illic, A. (2009). Sensor based condition monitoring. *Building Radio frequency IDentification for the Global Environment (Bridge) Euro RFID project*.
- Bughin, J., Hazan, E., Ramaswamy, S., Chui, M., Allas, T., Dahlström, P., ... & Trench, M. (2018). Skill shift: Automation and the future of the workforce. McKinsey Global Institute.
- Burritt, R. L., & Schaltegger, S. (2010). Sustainability accounting and reporting: Fad or trend? *Accounting, Auditing & Accountability Journal, 23*(7), 829-846.
- Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management, 38*(5), 360-387.
- Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management, 38*(5), 360-387.
- Case Study—Walmart. Table of Contents—TL;DR 1. Who owns… | *by R B Srikanth | Medium*. (n.d.). Retrieved October 15, 2024, from https://medium.com/@r.b.srikanth/walmart-2870d4b2056
- Chalmeta, R., & Barqueros-Muñoz, J-E. (2021). Using Big Data for Sustainability in Supply Chain Management. *Sustainability*, *13*(13). doi:10.3390/su13137004
- Chalmeta, R., & deLeon, M. (2020). The impact of digitalization on supply chain management: An operational efficiency perspective. *Journal of Industrial Engineering and Management, 13*(1), 28-41.
- Chalmeta, R., & deLeon, M. (2020). The impact of digitalization on supply chain management: An operational efficiency perspective. *Journal of Industrial Engineering and Management, 13*(1), 28-41.
- Chalmeta, R., & deLeón, N.J. (2020). Sustainable Supply Chain in the Era of Industry 4.0 and Big Data:A Systematic Analysis of Literature and Research. *Sustainability*, *12*(10). doi:10.3390/su12104108
- Chen, L., & Jia, G. (2017). Environmental efficiency analysis of China's regional industry: a data envelopment analysis (DEA) based approach. *Journal of Cleaner Production, 142*(2), 846-853. doi: 10.1016/j.jclepro.2016.01.045

- Choi, T. M., Wallace, S. W., & Wang, Y. (2018). Big data analytics in operations management. Production and Operations Management, 27(10), 1868-1883.
- Chow, G., Heaver, T. D., & Henriksson, L. E. *(1994). Logistics performance. International journal of physical distribution & logistics management.*
- Christopher, M., & Peck, H. (2004). Building the resilient supply chain.
- Christopher, M., & Peck, H. (2004). Building the resilient supply chain.
- Cioffi, R., Travaglioni, M., Piscitelli, G., Petrillo, A., & De Felice, F. (2020). Artificial Intelligence and Machine Learning Applications in Smart Production: Progress, Trends, and Directions. *Sustainability*, *12*(2). doi:10.3390/su12020492
- Cohen, M.A. and Lee, H.L. (1988*). Strategic analysis of integrated production-distribution systems: models and methods. Operations Research, Vol. 36 No. 2, pp. 216-28.*
- Doguc, (2020). Robot Process Automation (RPA) and Its Future. *Handbook of Research on Strategic Fit and Design in Business Ecosystems.*
- Downie, J., & Stubbs, W. (2013). Corporate carbon strategies and greenhouse gas emission assessments: The implications of scope 3 measurement. *Management Accounting Research, 24*(4), 344-359.
- Drucker, P.F. (1962). The economy's dark continent. *Fortune*, April
- Eccles, R. G., Ioannou, I., & Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. Management Science, 60(11), 2835-2857.
- Eccles, R. G., Ioannou, I., & Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. *Management Science, 60*(11), 2835-2857.
- Elkington, J. (1998). Cannibals with forks: The triple bottom line of 21st century business. New Society Publishers.
- Engström, R., & Johannesson, H. (2018). IKEA's sustainability strategy. Journal of Cleaner Production, 182, 508-518.
- Epstein, M. J., & Buhovac, A. R. (2014). Making sustainability work: Best practices in managing and measuring corporate social, environmental, and economic impacts (2nd ed.). Berrett-Koehler Publishers.

- Epstein, M. J., & Buhovac, A. R. (2014). *Making sustainability work: Best practices in managing and measuring corporate social, environmental, and economic impacts* (2nd ed.). Berrett-Koehler Publishers.
- Esmaeiliana, B., Sarkisb, J., Lewis, K., & Behdadd, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation & Recycling, 163.* doi: 10.1016/j.resconrec.2020.105064
- Esmaeiliana, B., Sarkisb, J., Lewis, K., & Behdadd, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation & Recycling, 163.* doi:10.1016/j.resconrec.2020.105064
- Esty, D. C., & Winston, A. S. (2009). Green to gold: How smart companies use environmental strategy to innovate, create value, and build competitive advantage. Yale University Press.
- Esty, D. C., & Winston, A. S. (2009). *Green to gold: How smart companies use environmental strategy to innovate, create value, and build competitive advantage*. Yale University Press.
- Ferrell, O. C., Fraedrich, J., & Ferrell, L. (2010). *Business ethics: Ethical decision making and cases* (8th ed.). South-Western Cengage Learning.
- Fonseca, L. M. (2018). Industry 4.0 and the digital society: concepts, dimensions and envisioned benefits. *Proceedings of the International Conference on Business Excellence, 12(1),* 386-397. doi:10.2478/picbe-2018-0034
- Frederico, G. F., Garza-Reyes, J. A., Anosike, A., & Kumar, V. (2019). Supply Chain 4.0: concepts, maturity and research agenda. *Supply Chain Management: An International Journal*
- GE. (2011). Ecomagination Annual Report. Retrieved from https://www.ge.com/sustainability/ecomagination
- Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048
- Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, 114*, 11-32.

- Gibassier, D., & Schaltegger, S. (2015). Carbon management accounting and reporting in practice: A case study on converging emergent approaches. Sustainability Accounting, Management and Policy Journal, 6(3), 340-365.
- Gleick, P. H. (2003). Water use. *Annual Review of Environment and Resources, 28*(1), 275-314.
- Görçün, O. F. (2022). Autonomous Robots and Utilization in Logistics Process. In O.F Görçün, & I.İyigün (Eds.), Logistics 4.0 and Future of Supply Chains (pp. 83-95). Singapore: Springer.
- Grieves, M., & Vickers, J. (2016). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches (pp. 85–113). Springer International Publishing. https://doi.org/10.1007/978-3-319-38756-7_4
- Grieves, M., & Vickers, J. (2017). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In Transdisciplinary Perspectives on Complex Systems (pp. 85-113). Springer, Cham.
- Groumpos, P. P. (2021*). A Critical Historical and Scientific Overview of all Industrial Revolutions. IFAC- PapersOnLine, 54(13), 464–471. doi:10.1016/j.ifacol.2021.10.492*
- Hahn, T., & Figge, F. (2011). Beyond the bounded instrumentality in current corporate sustainability research: Toward an inclusive notion of profitability. *Journal of Business Ethics, 104*(3), 325-345.
- Handfield, R.B., (1994*). US global sourcing: patterns of development. International Journal of Operations & Production Management 14, 40–51.*
- Heskett, J.L., Ivie, R.M. and Glaskowsky, N.A. Jr (1964). Business Logistics: Management of Physical Supply and Distribution. *The Ronald Press,* New York, NY.
- Hofmann, M., Neukart, F., & Bäck, T. (2017). Artificial Intelligence and Data Science in the Automotive Industry. Retrieved from https://www.researchgate.net/publication/319534479_Artificial_Intelligence_and_Data_Science_in_the_Automotive_Industry
- Houlihan, John B. (1988). International Supply Chains: A New Approach. *Management Decision,* Vol. 26, No. 3, pp. 13-19.
- How Can Data Quality Enhance Trust In Artificial Intelligence? (n.d.-a). Retrieved October 15, 2024, from

https://www.forbes.com/councils/forbestechcouncil/2020/08/17/how-can-data-quality-enhance-trust-in-artificial-intelligence/

- How Can Data Quality Enhance Trust In Artificial Intelligence*?* (n.d.-b). Retrieved October 15, 2024, from https://www.forbes.com/councils/forbestechcouncil/2020/08/17/how-can-data-quality-enhance-trust-in-artificial-intelligence/
- Hubbard, G. (2009). Measuring organizational performance: Beyond the triple bottom line. Business Strategy and the Environment, 18(3), 177-191.
- IBM. (n.d). *Blockchain success starts here.* Retrieved from https://www.ibm.com/topics/what-is-blockchain
- IKEA. (2018). People & Planet Positive: IKEA Sustainability Strategy. Retrieved from https://www.ikea.com/ms/en_JP/pdf/people_planet_positive.pdf
- Ishii, K., Takahashi, K. and Muramatsu*, R. (1988). Integrated production, inventory and distribution systems.International Journal of Production Research, Vol. 26 No. 3, pp. 473-82.*
- Ivanov, D., Tsipoulanidis, A., & Schönberger, J. (2019). Global supply chain and operations management. Springer International Publishing.
- *Jain, V. N. (2019). Robotics for Supply Chain and Manufacturing Industries and Future It Holds. International Journal of Engineering and Technical Research, 8(3). doi:10.17577/IJERTV8IS030062*
- Jarrahi, M. H. (2018). Artificial Intelligence and the Future of Work: Human-AI Symbiosis in Organizational Decision Making. *Business Horizons, 61*(4). doi: 10.1016/j.bushor.2018.03.007
- Johnson, M. P., & Schaltegger, S. (2016). Two decades of sustainability management tools for SMEs: How far have we come? *Journal of Small Business Management, 54*(2), 481-505.
- Kamble, S.S., Gunasekaran, A., Subramanian, N., Ghadge, A., Belhadi, A., & Venkatesh, M. (2021). Blockchain technology's impact on supply chain integration and sustainable supply chain performance: evidence from the automotive industry. *Annals of Operations Research*. doi:10.1007/s10479-021- 04129-6
- Kazançoğlu, I., Kazançoğlu, Y., Özbiltekin, M., Mangla, S. K., & Kumar, A. (2022). Using emerging technologies to improve the sustainability and resilience of supply

chains in a fuzzy environment in the context of COVID-19. *Annals of Operations Research.* doi:10.1007/s10479-022-04775-4

- Kazançoğlu, I., Kazançoğlu, Y., Özbiltekin, M., Mangla, S. K., & Kumar, A. (2022). Using emerging technologies to improve the sustainability and resilience of supply chains in a fuzzy environment in the context of COVID-19. *Annals of Operations Research.* doi:10.1007/s10479-022-04775-4

- Kazancoglu, Y., Ozkan-Ozen, Y. D., Ozbiltekin, M., & Weber, G. W. (2022). The role of big data analytics in sustainable supply chain management: A case study approach. *Sustainability, 14*(2), 710.
- Kazancoglu, Y., Ozkan-Ozen, Y. D., Ozbiltekin, M., & Weber, G. W. (2022). The role of big data analytics in sustainable supply chain management: A case study approach. *Sustainability, 14*(2), 710.
- Kiron, D., Kruschwitz, N., Haanaes, K., Reeves, M., & Goh, E. (2013). The Innovation Bottom Line: 2013 MIT Sloan Management Review Sustainability & Innovation Global Executive Study. MIT Sloan Management Review.
- Koleva, N. (2018). Industry 4.0's opportunities and challenges for production engineering and management. *INTERNATIONAL SCIENTIFIC JOURNAL "INNOVATIONS",* *6*(1), 17-18. Retrieved from https://stumejournals.com/journals/innovations/2018/1/17.full.pdf
- Koleva, N. (2018). Industry 4.0's opportunities and challenges for production engineering and management. *INTERNATIONAL SCIENTIFIC JOURNAL "INNOVATIONS",* *6*(1), 17-18. Retrieved from https://stumejournals.com/journals/innovations/2018/1/17.full.pdf

- Konrad, A. M., Yang, Y., & Maurer, C. C. (2006). An empirical exploration of the multiple and intersecting dimensions of diversity in the workplace. *Human Resource Management, 45*(3), 299-308.
- Koricanac, I. (2021). Impact of AI on the Automobile Industry in the U.S. *SSRN Electronic* Journal. doi:10.2139/ssrn.3841426
- Kouhizadeh M., Sarkis J., & Zhu Q. (2019). Nexus of Blockchain Technology, the Circular Economy, and Product Deletion. *Applied Sciences*, *9*(8). doi:10.3390/app9081712

- Kouhizadeh, M., Sarkis, J., & Zhu, Q. (2019). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics, 217*, 455-467.


- Kouhizadeh, M., Sarkis, J., & Zhu, Q. (2019). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics, 217*, 455-467.


- Kousi, N., Koukas, S., Michalos, G., Makris, S., & Chryssolouris, G. (2016). Oriented Architecture for Dynamic Scheduling of Mobile Robots for Material Supply. *Procedia CIRP*, *55*, 18-22. doi:10.1016/j.procir.2016.09.014
- Kshetri, N. (2017). Blockchain's roles in strengthening cybersecurity and protecting privacy. Telecommunications Policy, 41(10), 1027-1038. doi:10.1016/j.telpol.2017.09.003
- Kshetri, N. (2017). Can blockchain strengthen the internet of things? IT Professional, 19(4), 68-72.
- LaLonde, B.J. and Zinzer, P.H. (1976). Customer Service: Meaning and Measurement. *National Council of Physical Distribution* Management, Chicago, IL.
- Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. *Industrial marketing management*, *29*(1), 65-83.
- Lee, H.L. and Feitzinger, E. (1995*). Product configuration and postponement for supply chain efficiency.Institute of Industrial Engineers, Fourth Industrial Engineering Research Conference Proceedings,pp. 43-8.*
- Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons*, *58*(4), 431-440.
- Lee, I., & Lee, K. (2015). The Internet of Things (IoT): Applications, investments, and challenges for enterprises. Business Horizons, 58(4), 431-440.
- Mageto, J. (2021). Big Data Analytics in Sustainable Supply Chain Management: A Focus on Manufacturing Supply Chains. *Sustainability*, *13*(13). doi:10.3390/su13137101
- Mayer, N., Gandhi, S. J., & Hecht, D. (2019). *An Understanding Of Artificial Intelligence Applications In The Automotive Industry Value Chain*. Huntsville: American Society for Engineering Management (ASEM). Retrieved from https://www.proquest.com/conference-papers-proceedings/understanding-artificial-intelligence/docview/2358191460/se-2

- Mayer, N., Gandhi, S. J., & Hecht, D. (2019). *An Understanding Of Artificial Intelligence Applications In The Automotive Industry Value Chain*. Huntsville: American Society for Engineering Management(ASEM). Retrieved from https://www.proquest.com/conference-papers-proceedings/understanding-artificial-intelligence/docview/2358191460/se-2
- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business logistics*, *22*(2), 1-25.
- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business Logistics, 22*(2), 1-25.
- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business Logistics, 22*(2), 1-25.
- Min, H. (2019). Blockchain technology for enhancing supply chain resilience. Business Horizons, 62(1), 35-45.
- Min, H. (2019). Blockchain technology for enhancing supply chain resilience. Business Horizons, 62(1), 35-45.
- Morioka, S. N., & Carvalho, M. M. (2016). Measuring sustainability in practice: Exploring the inclusion of sustainability into corporate performance systems in Brazilian case studies. *Journal of Cleaner Production, 136*(Part A), 123-133.
- Most materials are recyclable, so why can't children's toys be sustainable? (2023, May 8). Yale Environment Review. https://environment-review.yale.edu/most-materials-are-recyclable-so-why-cant-childrens-toys-be-sustainable
- Müller, J. M., Kiel, D., & Voigt, K. I. (2018). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. Sustainability, 10(1), 247.
- Munir, M.A., Habib, M.S., Hussain, A., Shahbaz, M.A., Qamar, A., Masood,T.,...Salman, C.A. (2022).Blockchain Adoption for Sustainable Supply Chain Management: Economic, Environmental, and Social Perspectives. *Front. Energy Res, 10.* doi:10.3389/fenrg.2022.899632

- Nguyen, T., Li, Z. H. O. U., Spiegler, V., Ieromonachou, P., & Lin, Y. (2018). Big Data analytics in supply chain management: a state-of-the-art literature review. *Computers & Operations Research*, *98*, 254–264. doi: 10.1016/j.cor.2017.07.004
- Nicolae, A., Korodi, A., & Silea, I. (2019). An Overview of Industry 4.0 Development Directions in the Industrial Internet of Things Conte. *Romanian Journal of Information Science and Technology*, *22*(3/4), 183-201. Retrieved from https://www.romjist.ro/full-texts/paper627.pdf
- Nicolae, A., Korodi, A., & Silea, I. (2019). An Overview of Industry 4.0 Development Directions in the Industrial Internet of Things Conte. *Romanian Journal of Information Science and Technology*, *22*(3/4),183-201. Retrieved from https://www.romjist.ro/full-texts/paper627.pdf
- Nike. (2020). Move to Zero: Nike's Journey Toward Zero Carbon and Zero Waste. Retrieved from https://purpose.nike.com/move-to-zero
- Nunan, D., & Di Domenico, M. (2013). Market research and the ethics of big data. International Journal of Market Research, 55(4), 505-520.
- Paliwal, V., Chandra, S., & Sharma, S. (2020). Blockchain Technology for Sustainable Supply Chain Management: A Systematic Literature Review and a Classification Framework. *Sustainability*, *12*(18). doi:10.3390/su12187638
- Patagonia—Aviana Global. (2018, August 17). https://avianaglobal.com/portfolio/patagonia/
- Patagonia's AI-Powered Journey—MARSS. (n.d.). Retrieved October 15, 2024, from https://marss.amsterdam/branding-vs-marketing-copy-copy-2/
- Patterson, M. G. (1996). What is energy efficiency?: Concepts, indicators and methodological issues. *Energy Policy, 24*(5), 377-390.
- Pereira, A. C., & Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0 Concept. *Procedia Manufacturing, 13,* 1206-121. doi:10.1016/j.promfg.2017.09.032

  performance of supply chains: Review and sustainability supply chain management framework. *Supply Chain Management*, *19*(3), 232-241. doi:10.1108/SCM-02-2014-0061
- Plambeck, E. L., & Denend, L. (2011). The greening of Walmart's supply chain. Stanford Graduate School of Business Case Study.

- Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. Harvard Business Review, 92(11), 64-88.
- Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. Harvard Business Review, 92(11), 64-88.
- Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. Harvard Business Review, 92(11), 64-88.
- Porter, M. E., & Kramer, M. R. (2011). Creating shared value: How to reinvent capitalism—and unleash a wave of innovation and growth. Harvard Business Review, 89(1/2), 62-77.
- Porter, M. E., & Kramer, M. R. (2011). Creating shared value: How to reinvent capitalism—and unleash a wave of innovation and growth. *Harvard Business Review, 89*(1/2), 62-77.
- Porter, M. E., & Kramer, M. R. (2011). Creating shared value. Harvard Business Review, 89(1/2), 62-77.
- Prajogo, D., & Sohal, A. (2013). Supply chain professionals: A study of competencies, use of technologies,and future challenges. *International Journal of Operations & Production Management*, *33*(11-12), 1532-1554.
- Queiroz, M. M., Ivanov, D., Dolgui, A., & Wamba, S. F. (2020). Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literatur review. *Annals of Operations Research*, 1–38. doi:10.1007/s10479-020-03685-7
- Rangan, V. K., Chase, L., & Karim, S. (2015). The Truth About CSR. Harvard Business Review.
- Reddy, K. R. K., Gunasekaran, A., Kalpana, P., & Sreedharan, V. R. (2021). Developing a blockchain framework for the automotive supply chain: A systematic review. *Computers & Industrial Engineering,*. doi: 10.1016/j.cie.2021.107334
- Rejeb, A., & Rejeb, K. (2020). Blockchain and Supply Chain Sustainability. *Scientific Journal of Logistics*, *16*(3), 363-372. doi:10.17270/J.LOG.2020.467
- Robson, L. S., Clarke, J. A., Cullen, K. E., Bielecky, A. R
- Rojko, A. (2017). Industry 4.0 Concept: Background and Overview. *International Journal of Interactive Mobile Technologies*, *11*(5). doi:10.3991/ijim. v11i5.707
- Rojko, A. (2017). Industry 4.0 concept: background and overview. *International Journal of Interactive Mobile Technologies*, *11*(5), 77-90.

- Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International Journal of Interactive Mobile Technologies, 11*(5), 77-90.


- Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International Journal of Interactive Mobile Technologies, 11*(5), 77-90.


- Ross, J. W., Beath, C. M., & Mocker, M. (2016). Designed for digital: How to architect your business for sustained success. MIT Sloan Management Review.
- Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), 2117-2135.


- Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), 2117-2135.


- Salois, G. (2022, May 9). *Patagonia demonstrates how digitization helps both the environment and the bottom line*. Digital Commerce 360. https://www.digitalcommerce360.com/2022/05/09/patagonia-hang-tags/
- *SAP, Unilever pilot blockchain technology supporting deforestation-free palm oil*. (2022, March 21). Unilever. https://www.unilever.com/news/press-and-media/press-releases/2022/sap-unilever-pilot-blockchain-technology-supporting-deforestationfree-palm-oil/
- Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. *International Journal of Production Economics, 130*(1), 1-15.


- Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. *International Journal of Production Economics, 130*(1), 1-15.


- Schaltegger, S., & Burritt, R. (2018). Business cases and corporate engagement with sustainability: Differentiating ethical motivations. *Journal of Business Ethics, 147*(2), 241-259.

  Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research, 57*(7), 2117-2135. doi:10.1080/00207543.2018.1533261
- Schmidt, R., Möhring, M., Härting, R-C., Reichstein, C., Neumaier, P., & Jozinović, P. (2015). Industry 4.0 - Potentials for Creating Smart Products: Empirical Research

Results. *International Conference onBusiness Information Systems,* 16-27. doi:10.1007/978-3-319-19027-3_2

- Schulze-Horn, I., Hueren, S., Scheffler, P., & Schiele, H. (2020). Artificial Intelligence in Purchasing: Facilitating Mechanism Design-based Negotiations. *An International Journal, 34*(8), 618-642.doi:10.1080/08839514.2020.1749337
- Scott, J.A., Ho, W., & Dey, P.K. (2013). Strategic sourcing in the UK bioenergy industry. *International Journal of Production Economics*, *146*(2),478-490. doi:10.1016/j.ijpe.2013.01.027
- Searcy, C. (2012). Corporate sustainability performance measurement systems: A review and research agenda. Journal of Business Ethics, 107(3), 239-253.
- Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production, 16*(15), 1699-1710.
- Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production, 16*(15), 1699-1710.
- Shamout, M., Ben-Abdallahb, R., Alshurideha, M. T., Alzoubid, H. M., Kurdie, B. A., & Hamadnehc, S. (2022). A Conceptual Model for the Adoption of Autonomous Robots in the Supply Chain and Logistics Industry. *Uncertain Supply Chain Management*, *10*(2), 577-592. doi: 10.5267/j.uscm.2021.11.006
- Sharma, A., & Singh, B. J. (2020*). Evolution of Industrial Revolutions: A Review. International Journal of Innovative Technology and Exploring Engineering, 9(11), 66-73. doi: 10.35940/ijitee.I7144.0991120*
- Sishi, M. N., & Telukdarie, A. (2021). Supply Chain Energy Sustainability with Artificial Intelligence. *IEEE Technology & Engineering Management Conference - Europe (TEMSCON-EUR),* 1-6. doi:10.1109/TEMSCON-EUR52034.2021.9488609
- Sriraman, N. (n.d.). *Council Post: How Can Data Quality Enhance Trust In Artificial Intelligence?* Forbes. Retrieved October 15, 2024, from https://www.forbes.com/councils/forbestechcouncil/2020/08/17/how-can-data-quality-enhance-trust-in-artificial-intelligence/
- Stevens, G. C. (1989). Integrating the supply chain. *International Journal of physical distribution & Materials Management*.

- Stevens, G. C. (1989). Integrating the supply chain. *International Journal of physical distribution & Materials Management*.
- Sun, X., Yu, H., Solvang, W. D., Wang, Y., & Wang, K. (2022). The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities. *Environmental Science and Pollution Research, 29,* 9560-9591. doi:10.1007/s11356-021-17693-y
- Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology, 94*(9), 3563-3576.
- Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology, 94*(9), 3563-3576.
- Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art. IEEE Transactions on Industrial Informatics, 15(4), 2405-2415.
- Tapscott, D., & Tapscott, A. (2017). How blockchain is changing finance. Harvard Business Review, 1(9), 2-5.
- Tay, S. I., Chuan, L. T., Aziati, A. H. N., & Ahmad, A. N. A. (2018). An Overview of Industry 4.0: Definition, Components, and Government Initiatives. *Journal of Advanced Research in Dynamical and Control Systems, 10*(14), 1379-1387. Retrieved from https://www.researchgate.net/publication/332440369
- *The Death of a Toy Retailer: How a Lack of Digital Transformation Helped Destroy Toys "R" Us | Inc.com*. (n.d.). Retrieved October 15, 2024, from https://www.inc.com/jason-albanese/the-death-of-a-toy-retailer-how-a-lack-of-digital-transformation-helped-destroy-toys-r-us.html
- Thomas, D. J., & Griffin, P. M. (1996). Coordinated supply chain management. *European journal of operational research*, *94*(1), 1-15.
- Tirkolaee, E. B., Sadeghi, S., Mooseloo, F. M., Vandchali, H. R., & Aeini, S. (2021). Application of Machine Learning in Supply Chain Management: A Comprehensive Overview of the Main Areas. *Mathematical Problems in Engineering, 21,* 1-14. doi:10.1155/2021/1476043
- *TM1/Planning Analytics—Aviana Global*. (2018, September 21). https://avianaglobal.com/tm1-planning-analytics/

- Tsai, F. M., Bui, T.-D., Tseng, M.-L., Ali, M. H., Lim, M. K., & Chiu, A. S. (2021). Sustainable Supply Chain Management Trends in World Regions: A DataDriven Analysis. *Resour. Conservation Recycl*,*167*. doi: 10.1016/j.resconrec.2021.105421
- Tsai, W. H., Chen, H. C., Lin, H. J., & Wang, S. Y. (2021). Blockchain technology for sustainable supply chains: A systematic literature review on applications and challenges. *Sustainability, 13*(2), 402.
- Tsai, W. H., Chen, H. C., Lin, H. J., & Wang, S. Y. (2021). Blockchain technology for sustainable supply chains: A systematic literature review on applications and challenges. *Sustainability, 13*(2), 402.
- Tung, C. M. (2018). Vertical integration for smart manufacturing-The dynamic capability perspective. *Journal of Advances in Technology and Engineering Research, 4(2),*70-78. doi:10.20474/jater-4.2.3
- Tzafestas, S. and Kapsiotis*, G. (1994). Coordinated control of manufacturing/supply chains using multi-level techniques. Computer Integrated Manufacturing Systems, Vol. 7 No. 3, pp. 206-12.*
- *Unilever Sustainable Living Plan 2010 to 2020*. (2010).
- Unilever. (2014). Unilever Sustainable Living Plan: Five Years of Progress. Retrieved from https://www.unilever.com/sustainable-living/
- *Unilever's People-First Transformation And The AI Flywheel*. (n.d.). Retrieved October 15, 2024, from https://www.forbes.com/sites/kevinomarah/2023/10/26/unilevers-people-first-transformation-and-the-ai-flywheel/
- Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425-478.
- Verdouw, C. N., Wolfert, J., Beulens, A. J. M., & Rialland, A. (2016). Virtualization of food supply chains with the internet of things. Journal of Food Engineering, 176, 128-136.
- Vinitha, K., Ambrose Prabhu, R., Bhaskar, R., & Hariharan, R. (2020). Review on industrial mathematics and materials at Industry 1.0 to Industry 4.0. *Materials Today: Proceedings, 33*(7), 3956–3960. doi: 10.1016/j.matpr.2020.06.33
- Viswanadham, N. (2002). The past, present, and future of supply-chain automation. *IEEE Robotics & Automation Magazine*, *9*(2), 48-56.

- Walmart. (2012). Walmart's Sustainability Index: Tracking Progress in 2012. Retrieved from https://corporate.walmart.com/media-library/document/sustainability-index-update-january-2012/_proxyDocument?id=0000015a-3da7-dca8-a3fa-7fffcf3d0001
- Wamba, S. F., Dubey, R., Gunasekaran, A., & Akter, S. (2020). The performance effects of big data analytics and supply chain ambidexterity: The moderating effect of environmental dynamism. *International Journal of Production Economics, 222,* 107498. doi:10.1016/j.ijpe.2019.09.019
- Wang, G., Gunasekaran, A., Ngai, E. W., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. International Journal of Production Economics, 176, 98-110.
- Wang, G., Gunasekaran, A., Ngai, E., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International Journal of Production Economics, 176,* 98-110. doi:10.1016/j.ijpe.2016.03.014
- Xu, L. D., He, W., & Li, S. (2014). Internet of Things in industries: A survey. IEEE Transactions on Industrial Informatics, 10(4), 2233-2243.
- Yahiaoui, S., Fedouaki, F., & Mouchtachi, A. (2020). How Blockchain Make Better the Supply Chain in the Automotive Industry. *International Journal of Engineering and Advanced Technology*, *9*(3). doi:10.35940/ijeat.C5208.029320
- Zhang, A., & Wang, H. (2019). Benefits and challenges of big data in the accounting profession: Analysis of big data research in accounting from 1970 to 2018. Journal of Data Information and Management, 1(1), 1-21. doi:10.1007/s42488-019-00001-z
- Zhang, L., Zhu, Q., & Sarkis, J. (2019). A literature review and future research directions on blockchain and supply chain sustainability. Resources, Conservation, and Recycling, 151, 104279.
- Zhou, Q., Jiang, W., & Yao, J. (2018). An IoT-enabled safety decision support system for construction site safety monitoring. International Journal of Environmental Research and Public Health, 15(12), 2858.
- Zhu, C., Du, J., Shahzad, F., & Watoo, M.U. Sustainability Is a Corporate Social Responsibility: Measuring the Nexus between Sustainable Supply Chain Management, Big Data Analytics Capabilities, and Organizational Performance. *Sustainability,14.* doi:10.3390/su14063379