Application of Artificial Intelligence in Supply Chain Management

Dmitrii Khimanych

Haaga-Helia University of Applied Sciences
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Author(s)
Dmitrii Khimanych

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Modern societies rely heavily on efficient supply chains to deliver products and services. Currently, supply chain management (SCM) faces multiple challenges such as external disruptions, modern technology integration, cost pressures, and sustainability demands. Artificial Intelligence (AI), a significant development from the digital and industrial revolutions, holds tremendous potential to address these challenges.

This thesis aims to explore how AI can be applied in SCM and the value and benefits it provides. Additionally, it seeks to identify the key challenges associated with integrating and utilizing AI in SCM, thus providing a room for proactive preparation strategies.

Data for this study were collected using two main methods: first, through seven semi-structured interviews with industry professionals, and second, by reviewing and analysing digitally available interviews related to AI applications in SCM.

The analysis identifies specific areas within SCM where AI has been beneficial, highlighting improvements such as enhanced speed and accuracy, significant cost reductions, streamlined process automation, increased transparency, reduced manual labour, and improved customer satisfaction.

Furthermore, it discusses the obstacles to AI adoption in SCM, such as issues related to data quality, system integration, lack of expertise, resistance to organizational change, and the associated financial challenges.

The study provides a snapshot of the varying levels of AI application in SCM, from minimal to advanced and offers valuable insights, underscoring the dynamic and transformative impact of AI on supply chain management practices.

Keywords
Supply Chain Management, Artificial Intelligence, Machine Learning, Digitalization, Transformation

List of Abbreviations

To make it easier for the reader, a glossary of abbreviations is provided.

AI	Artificial intelligence
SC	Supply Chain
SCM	Supply Chain Management
ML	Machine Learning
IoT	Internet-of-Things
ES	Expert System
GA	Genetic Algorithm
ANN	Artificial Neural Networks
FL	Fuzzy Logic
NLP	Natural Language Processing
CV	Computer Vision
ERP	Enterprise Resource Planning
IT	Information Technology
API	Application Programming Interface
GDP	Gross Domestic Product
SCOR	Supply Chain Operations Reference (Model)
ASCM	The Association for Supply Chain Management
KPI	Key Performance Indicator
SME	Small and Medium-Sized Enterprise
EU	European Union
RQ	Research Question

Contents

1 Introduction

The opening chapter of the thesis provides a comprehensive introduction, setting the stage for the subsequent analysis by detailing the research topic and offering appropriate background information. It clearly articulates the problem statement and outlines the chosen research methods and scope. This chapter then describes the objectives of the study, formulating specific research questions. It concludes by acknowledging potential limitations of the study, ensuring a clear understanding of the scope and boundaries of the research conducted.

1.1 Background

Over the past few decades, there have been significant advancements in the field of artificial intelligence (AI). AI is transitioning from a theoretical academic domain to a practical aspect of business operations. An increasing number of AI applications are beginning to emerge across various industries, including customer relations, transportation, healthcare, and supply chain management. This raises a logical question: How can AI benefit these industries, tasks, and domains? This study aims to explore how AI can support supply chain management, examining the applications already implemented in organizations and identifying future opportunities for the coming years.

We live in times when new technology, such as AI, is having a transformational effect on the lives of individuals, governments and companies. A well-known consulting company PwC estimates that by 2030 there will be +26 % GDP growth for local economies from AI which represent + 15.7 trillion US Dollars (PricewaterhouseCoopers, 2021). While AI opens a wide range of opportunities to solve serious global problems like climate change and food security, at the same time it brings big risks and hazards that require careful considerations.

Supply chains (SC) play a significant role in the overall economic growth and directly affects well-being of citizens. Nowadays supply chain management (SCM) is grappling with the complexities, and this is where AI can help. AI can optimize transportation, automate warehouse, logistics and manufacturing operations, significantly reduce errors, provide rich analytics and accurate forecasting, contribute to better product quality and many more. Embracing AI in SCM holds huge potential for increased productivity, profitability, and overall success. Therefore, it is important to develop knowledge and understanding about AI to allow for effective implementation in the future.

The thesis aims to contribute with guidance regarding the future of AI. The thesis aims to study how AI can be used in SCM. Want are the benefits and what are the real-life applications? Finally, what are the opportunities for the future?

The answers to these questions will be useful to a wide range of specialists and organizations who is interested in successful AI implementations.

1.2 Problem statement

Supply chain management (SCM) facilitates economic growth by ensuring the exchange of goods between firms and customers. The supply chain has effects on multiple organisational areas, including product creation, marketing, operations, distribution, finance, and customer support. SCM has numerous components that necessitate the use of systems and tools to optimise workflows, enhance productivity, and enhance precision. Information systems are crucial for firms to effectively handle supply chains by coordinating schedules, acquiring resources, managing suppliers, and analysing data.

Nowadays, SCM faces numerous challenges, including disruptions like the COVID-19 pandemic, the war between Russia and Ukraine, energy crises, changing consumer behaviour, increased competition, high demand for sustainable practices, and the arrival of a circular economy requirements. These factors make it exceedingly difficult for supply chain professionals to maintain a smooth, uninterrupted flow of goods and services while remaining cost-efficient.

Professionals relying on traditional technologies may struggle to keep up with the rapid pace of changes. The integration of Artificial Intelligence (AI) presents a promising solution, albeit with some uncertainties and risks that require careful examination.

This thesis aims to explore the domain of AI applications in SCM to gain valuable insights on how AI can help solve contemporary challenges. It will examine AI's role in increasing efficiency, boosting service levels, enhancing resilience, and improving customer satisfaction.

1.3 Purpose and research questions

The main purpose of the study is to shed light on the ways AI technology can be beneficial to SCM professionals in achieving their goals. What impact AI technology brings already and what are the potential for the future. What is the real-life experience of adopting AI in various SCM domains and what are the future implications for SCM work.

There are two main questions aimed to be addressed on this thesis:

RQ1. How can AI be applied in Supply Chain Management, what value and benefits does it offer?

RQ2. What are the key challenges associated with the integration and utilization of AI in SCM?

1.4 Limitations

The current research has some limitations. First, to be fully fluent and expert in AI domain a specialized education is needed which the author does not possess. Therefore, this subject is examined from a theoretical perspective. Second, the participants were chosen based on their expertise in SCM and AI. The sample size of the interview respondents is rather small since there is a scarcity of AI professionals in the supply chain business. Finally, AI technology and is very rapidly advancing and since it holds immerse potential there is some level of secrecy surrounding the topic. Hence, making a comprehensive evaluation of AI is challenging.

2 Theoretical background

The second chapter presents a comprehensive theoretical background for the study, addressing three central elements: artificial intelligence (AI), supply chain management (SCM), and the application of AI in SCM. The literature selected for review was rigorously examined and critically assessed to ensure relevance and depth. This chapter is structured to align with the research objectives, effectively integrating AI with SCM practices. Overall, the theoretical framework established in this chapter lays a solid foundation for the thesis, offering a comprehensive understanding of the key concepts involved.

2.1 Artificial Intelligence (AI)

This sub-chapter begins with an introduction to Artificial Intelligence (AI), providing a clear definition and explanation of the concept. It then explores the main benefits derived from AI. After this, the discussion shifts to the potential risks and challenges associated with AI implementation, offering a balanced view on the phenomena. The chapter concludes by illustrating the future potentials of AI, highlighting anticipated developments and their implications. The sub-chapter offers a comprehensive understanding of AI's role and significance in the modern digital world.

2.1.1 What is AI

Technology has driven economic progress for many years. It has been continuously changing societies and economies. Examples from history include the Industrial Revolution, which transformed economy from agrarian to industrial one and the electricity, which enabled mass production and communications. Each technology advance had a profound effect on the labour markets, consumer behaviour, and economies.

Nowadays, the digital revolution has become the leading force in technological progress. It is rapidly transforming industries and economies. The incorporation of digital technologies into daily life and business activities has brought huge improvements in efficiency and the arrival of innovative business models. The emergence of e-commerce platforms such as Amazon has completely transformed the retail sector, illustrating the considerable influence of digital technology on our lives (Kannan & Li, 2017, pp. 22–25).

Artificial Intelligence (AI) is a notable and powerful invention resulting from the digital and industrial revolutions. The implementation of AI in several industries brings significant advancement towards automating tasks and enhancing decision-making. AI technologies, such as machine learning and deep learning, possess the ability to analyse massive quantities of data, identify patterns, and make predictions without support from humans. AI technology not only improves operating

efficiencies but also creates new innovative opportunities. For example, AI applications in medical diagnostic procedures can significantly enhance the precision and efficiency of disease detection (Topol, 2019, p. 44).

AI can be defined as the development and implementation of algorithms in computer systems to carry out activities that mimic human-like intellect. These encompass the acquisition of knowledge, the decision-making process, problem-solving, and the capacity to analyse information. John McCarthy coined the phrase "Artificial Intelligence" in 1956 during the Dartmouth Conference, that signified the beginning of AI as an academic discipline. This event set the foundation for extensive research and advancement, resulting in the development of algorithms that can replicate cognitive abilities, such as learning and problem-solving (Russell & Norivg, 2021, pp. 1–17).

The advancement of AI has been characterised by significant milestones, starting with the Turing Test introduced by Alan Turing in 1950 to assess a machine's capacity to display intelligent behaviour that cannot be distinguished from that of a human. Another milestone was the creation of neural networks in the 1980s, which imitate the interconnected neuron structure of the human brain to process information. The advancement in technology has led to the current era of machine learning and deep learning, which have enhanced the field of AI. This progress has enabled the development of various applications, such as natural language processing and autonomous vehicles (Russell & Norivg, 2021, pp. 823, 907).

The diverse origins of AI include various fields such as philosophy, mathematics, economics, neurology, psychology, computer engineering, cybernetics, and linguistics. They effectively enabled AI to imitate human intellect and perform cognitive capabilities. Philosophical studies into the nature of awareness and understanding have built a theoretical framework for understanding intelligence. At the same time, mathematical principles have provided the basis for the algorithms that run artificial intelligence systems (Russell & Norivg, 2021, pp. 5–6). The use of economic models has had an impact on decision-making algorithms.

In addition, computer engineering has supplied the essential technological capabilities for constructing sophisticated AI systems. Cybernetics focused on studying communication and control in both living organisms and machines, which has become essential for the advancement of autonomous systems. Linguistics has been crucial in facilitating natural language processing, empowering AI to understand and use human language. The collaboration across these fields has advanced AI from theoretical research to practical applications (Poole & Mackworth, 2019, p. 9).

AI domains are closely interconnected, with techniques, applications, and industries all influencing each other in a dynamic way that promotes innovation and technological progress. The synergy is

highlighted by the fact that approximately 70 percent of AI-related inventions integrate methodologies and applications from various sectors, illustrating the adaptable and interdisciplinary nature of AI technology (WIPO, 2019, p. 15).

These combinations demonstrate AI's potential to enhance and transform traditional methods across various sectors. In the field of manufacturing, the combination of AI with robotics has resulted in the creation of smart factories. These factories are equipped with machines that can acquire knowledge from ongoing operations and continuously enhance production efficiency in real-time (Lee et al., 2015, pp. 176–177). The integration of Natural Language Processing (NLP) and AI in healthcare allows for the extraction of significant insights from unorganised patient data, which in turn enhances diagnostic precision (Jiang et al., 2017, pp. 230–231). In the financial industry, the combination of AI and blockchain technology is expected to bring about improved security and transparency in financial transactions. This has the potential to significantly change how businesses and consumers engage with financial institutions (Treleaven et al., 2017, pp. 15–16).

AI is a powerful force in today's digital age, with the ability to effectively analyse external data, learn from it, and use the knowledge gained to achieve specific goals and tasks. This makes AI highly influential in both social and economic domains. This concept captures the essence of AI’s power: its unparalleled ability to rapidly and thoroughly process and analyse vast amounts of data in real-time, thereby enabling more informed decision-making across diverse fields. The role of AI in driving efficiency and innovation is undeniable, as evidenced by its ability to enhance customer service through chatbots and use predictive analytics to optimise operations (Xu et al., 2017).

Despite being created over 70 years ago, AI only gained significant recognition in scholarly literature and the public domain within the last decade. The profound attention on AI primarily stems from its rapid advancements and significant achievements across multiple sectors. For example, in the field of supply chain management, AI is transforming the way companies predict demand, handle inventory, and streamline transportation. This holds a significant potential for improvements in efficiency and cost reductions (Min, 2010).

AI continues to drive innovation by automating tasks, enhancing decision-making, and providing insights that were previously unattainable. As AI technology advances, its influence is expected to grow, leading to more extensive integration across various industries and transforming traditional business models (Makridakis, 2017, p. 59).

Machine learning (ML) emerged as an essential approach within the field of AI. ML refers to the ability of computers to learn from specific training data, allowing them to automatically create analytical models and efficiently solve related tasks. ML goes beyond encoding knowledge into

computers, rather it seeks to automatically learn and extract meaningful relationships and patterns from examples and observations, adapting and improving with each new dataset. (Janiesch et al., 2021, p. 685). ML comprises a range of methodologies to address specific types of problems and datasets. These include supervised learning, which involves training a model on a labelled dataset; unsupervised learning, which focuses on unlabelled data and enables the model to autonomously identify patterns and relationships; and reinforcement learning, where the model learns decision-making through rewards or penalties (Jordan & Mitchell, 2015, p. 257).

Each of these ML types plays a significant role in advancing and implementing AI technology across various industries. Supervised learning is a crucial component in predictive modelling and classification tasks, such as speech recognition or fraud detection systems (Jordan & Mitchell, 2015, p. 257). Unsupervised learning is particularly effective in doing exploratory data analysis and clustering. It provides valuable insights into complex data without the need for prior labelling. Reinforcement learning plays. a crucial role in the development of systems that require making a series of judgements, such as autonomous vehicles and dynamic pricing models (Chen et al., 2022). Machine learning's adaptability allows for customisation of AI to match unique needs, enabling substantial developments.

AI is advancing fast, driving transformative changes across several industries. The rapid progress in this field is driven by significant improvements in computer capacity, the availability of data, and innovative algorithms. These advancements have empowered AI systems to handle progressively more complex tasks with unparalleled precision (Russell & Norivg, 2021, pp. 24–25). AI's immense potential is widely acknowledged by industry experts and scholars. It is projected to play a crucial role in driving future economic growth, societal changes, and technical innovation.

2.1.2 Benefits of AI

AI offers numerous advantages and has the capacity to transform various industries by improving effectiveness, precision, and output.

AI plays a substantial role in automating processes that are repetitive and time-consuming, thereby enabling human workers to concentrate on more innovative tasks (Josten & Lordan, 2022, p. 2). Automation encompasses a wide range of functions, from manufacturing assembly lines to administrative duties in offices, with the aim of making processes more efficient and minimising mistakes.

Next, AI plays a critical role a crucial function in data processing and decision-making. AI's ability to quickly scan and analyse vast amounts of data allows it to identify patterns and extract insights be-yond human capabilities. This enhances decision-making across various fields, including finance, healthcare, and urban planning. For example, in the field of healthcare, artificial intelligence

algorithms have the capability to forecast the occurrence of disease and help in in customizing medical treatments to individual patients (Esteva et al., 2019, p. 28).

An important advantage of AI is its ability to improve safety in cases that involve high levels of risk (Lee et al., 2015, p. 178). As an illustration, in the industrial sector, AI has the capability to continuously monitor operational conditions, accurately forecast equipment malfunctions, and initiate proactive maintenance to avoid accidents. Autonomous vehicles utilise AI algorithms to analyse information gathered from sensors and cameras, enabling them to make rapid judgements. This has the potential to decrease the number of traffic accidents caused by human mistakes (Makridakis, 2017, p. 51).

Moreover, AI improves consumer experiences by providing customised services. AI enables the provision of quick customer support through chatbots that are available 24/7, as well as recommendation engines on e-commerce platforms that customise ideas based on specific user preferences. This results in a more personalised and efficient customer experience (Huang & Rust, 2018, p. 161).

Another key advantage of AI is its capacity to drive innovation and create new opportunities for growth. AI technologies facilitate the creation of novel products and services that were previously inconceivable, ranging from virtual personal assistants capable of comprehending and anticipating our requirements to intelligent systems capable of composing music, generating artwork, and even writing news articles (Anantrasirichai & Bull, 2022). These inventions have a dual impact: they not only foster economic progress but also enhance human experiences and push the limits of creativity.

With the rapid advancement of AI, there is a promising future where its integration in various industries can improve efficiency, enhance quality of life, and generate economic benefits. Nevertheless, in addition to its potential, this rapid advancement also necessitates thoughtful examination of ethical considerations, worries about job displacement, and the requirement for strong regulation to guarantee its beneficial and fair implementation for the whole society.

2.1.3 Risks of using AI

Although the progress and advantages of AI are extensive, it is equally important to recognise and prepare for the potential hazards and difficulties linked to its adaption. Privacy problems, employment displacement, and ethical dilemmas are prominent issues among them.

Privacy concerns emerge due to the reliance of AI systems on extensive datasets, which may contain personal information. As AI becomes more assimilated into everyday life and company

processes, there is an increased risk of sensitive data being exploited or compromised, which can result in privacy and trust breaches (Tan et al., 2023).

AI poses a significant risk of job displacement. With the increasing capabilities of AI systems in completing tasks that were historically carried out by people, there is a genuine concern that several jobs may be automated, resulting in substantial changes in the workforce. Although certain positions may be generated during the transition, there is a possibility of a decline in employment for certain groups of people who lack the necessary abilities in an economy driven by AI (Frey & Osborne, 2017, pp. 254–255).

AI systems face difficulties when confronted with ethical challenges that need them to make judgements with moral consequences. For instance, within the realm of autonomous automobiles, AI is required to make judgements that have the potential to affect human lives. The issue of how AI should prioritise such decisions gives rise to delicate ethical topics that society must consider (Lin, 2016, pp. 73–82).

The bias in AI decision-making is another significant topic. The bias typically comes from the data used during the AI training. Once there are biases in the training dataset, the decisions made by the AI will mirror these biases, resulting in outcomes that are unfair or discriminating. There are multiple studies which confirms bias in the real-life cases. The problem is especially alarming in areas such as recruitment, lending, and law enforcement, as AI systems have the potential to preserve or even increase social inequalities (Rastogi et al., 2022).

The growing dependence on technology, enhanced by advanced AI, poses a potential risk of eroding human capacity for analytical thinking and problem-solving. With the increasing use of AI systems, there is a worry that humans can excessively depend on these systems, which could lead to a decline in the essential skills and talents necessary for innovation and adaptability in the face of unforeseen difficulties (Spector & Ma, 2019).

AI-enhanced cybersecurity threats represent a new problem. AI has the potential to develop advanced hacking tools that may surpass current cybersecurity solutions. This has the potential to result in an increase in effective cyber-attacks and breaches, which might pose substantial dangers to individuals, organisations, and national security (Taddeo & Floridi, 2018, pp. 297–298).

To successfully navigate the field of AI, adopting a collaborative and careful approach is crucial to achieve fair and secure outcomes for all stakeholders. It is essential to have close cooperation among developers, users, regulators, and the broader community. This collaborative approach will facilitate knowledge exchange, highlight potential challenges, and allow to achieve common goals.

2.1.4 Future potential of AI

The potential of AI to influence the future is extensive, encompassing a wide range of applications and possibilities. According to experts, there will be a significant and positive effect on many industries, leading to advancements, improved productivity, and finding the solution to the complex problems (Schwab, 2016, p. 127). AI is expected to bring a significant transformation in healthcare, particularly in the areas of diagnostics. IBM's Watson, for example, has already demonstrated its ability to diagnose cancer and provide personalised medical advice (Jiang et al., 2017). This has the potential to result in more precise diagnoses, customised treatments, and improved patient healthcare.

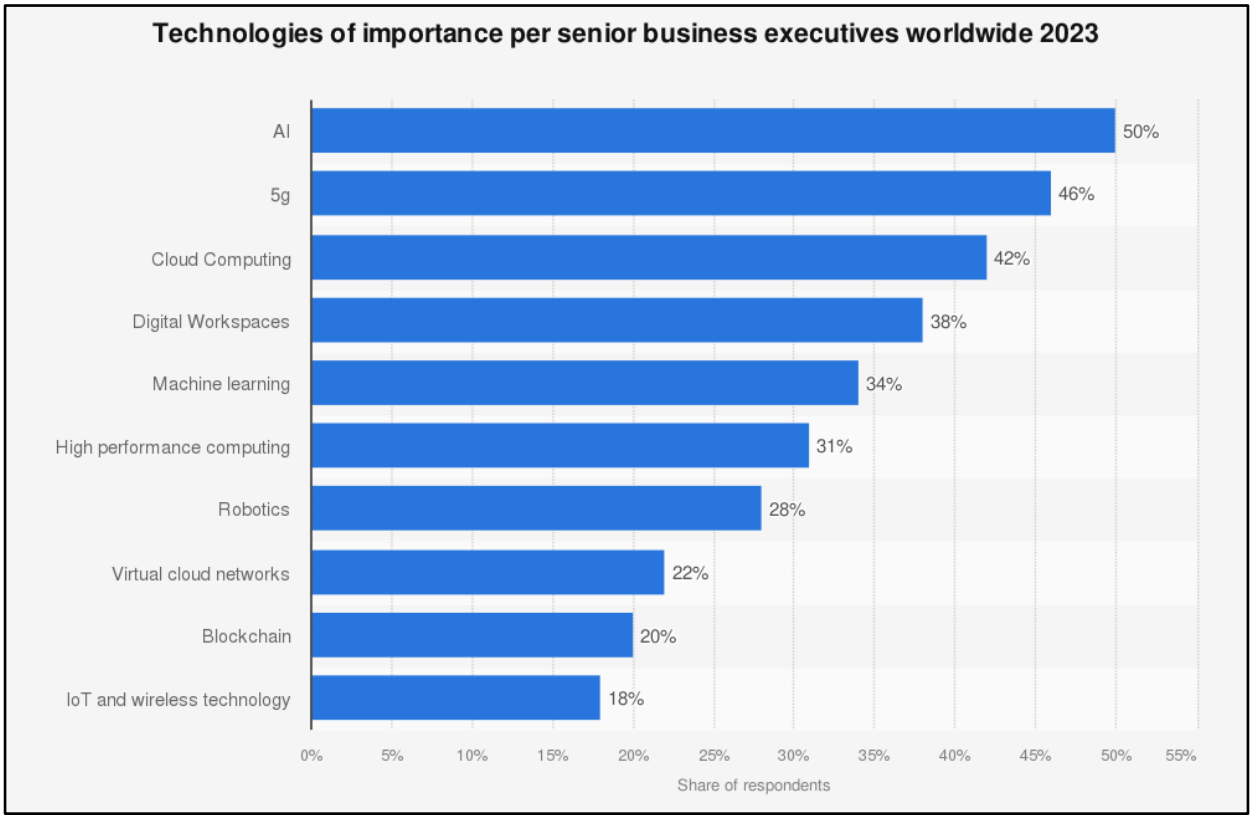

Figure 1. Technologies of importance per senior business executives worldwide 2023 (Thormundsson Bergur, 2024).

In a global survey conducted in 2023, 50 percent of the participants from various countries recognized artificial intelligence (AI) as a strategically important technology and planned to prioritize it in the upcoming years (Thormundsson Bergur, 2024), (Figure 1).

AI is expected to have a significant economic influence, potentially contributing $15.7 trillion to the world economy by 2030 according to PricewaterhouseCoopers estimates (Rao & Verweij, 2017, p. 3). This amount is equivalent to the GDP of China, the world's second-largest economy. This

remarkable value is anticipated because of AI-driven productivity optimization, the increase in customer demand through personalized and high-quality products, and the emergence of entirely new and unforeseen markets.

AI is expected to profoundly reshape the landscape of employment in the future. The automation of repetitive tasks holds the potential to free human labour for roles that are more innovative and strategically significant. According to a report published by McKinsey Global Institute in 2017, it is projected that AI technologies might automate approximately 50 % of today`s work activities. This automation can happen by 2055 with 20 years earlier or later depending on a range of factors (Bughin et al., 2017). This could lead to the displacement of a considerable number of individuals. A strategic and thoughtful approach to workforce development and skills training is essential to effectively navigate the job shifts resulting from AI advancements (Bughin et al., 2017).

AI technologies are anticipated to have a decisive impact on addressing climate change. AI can support ecological efforts by improving energy efficiency in smart grids, strengthening climate modelling forecasts, and optimizing the management of natural resources (Rolnick et al., 2019).

Experts predict that AI will significantly enhance global security by improving cybersecurity against sophisticated threats and using predictive analytics to prevent conflicts. However, these technological advances come with the responsibility to ensure ethical use and preventing AI from being employed for wrong purposes (Taddeo & Floridi, 2018, pp. 297–298).

Given the significant economic shifts AI brings, it is essential for politicians, businesses, and individuals to prepare for its dual impact: the potential for substantial economic growth and the need to address its disruptive effects on jobs.

2.2 Supply Chain Management (SCM)

This sub-chapter starts with an overview of supply chain management (SCM), introducing the SCOR model as a theoretical framework that outlines the key elements and objectives of SCM. This framework provides a robust basis for understanding the subsequent sections. The discussion then proceeds to the contemporary challenges and trends affecting SCM, positioning the topic with-in the context of current global realities. The role of technology as a pivotal enabler in addressing the SCM challenges is explored next, with the Gartner Hype Cycle Model for supply chain strategy serving as a guide to understand the readiness and impact of emerging technologies. The sub-chapter concludes with a forward-looking analysis of SCM's potential evolution in an increasingly digital future, providing a vision of how digital advancements may continue to transform the landscape of supply chain management.

2.2.1 SCM overview

Supply chains are the lifeblood of most, if not all, businesses today. The seamless coordination of each link in the supply chain is essential for organizations to meet delivery commitments and adapt to dynamic market demands, especially amidst disruptions like the COVID-19 pandemic. The section will provide definition and brief overview of supply chain and supply chain management with SCOR model, describe main goals, current trends, and pressing challenges. This will set up the stage for subsequent section on application of AI in SCM.

A supply chain encompasses all entities that are directly or indirectly involved in meeting a customer's request. The supply chain encompasses not just the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves. Within any organisation, such as a manufacturer. The supply chain encompasses all activities related to receiving and fulfilling consumer requests. The functions encompassed in this list are new product creation, marketing, operations, distribution, financing, and customer support (Chopra & Meindl, 2019, p. 13).

Supply chain management (SCM) is the management of all those tasks connected with the supply chain. It starts from managing all flows circulating in the company or between the environment and the company. These flows can be financial transactions, information, supply, delivery, storage, etc. (El Haoud & Bachiri, 2019, p. 1).

The Supply Chain Operations Reference (SCOR) model is one of the most widely accepted frameworks globally for describing supply chain management (ASCM, 2020). Developed by the Supply Chain Council, the SCOR model is widely recognized for its comprehensive approach that spans from the supplier's supplier to the customer's customer (Figure 2).

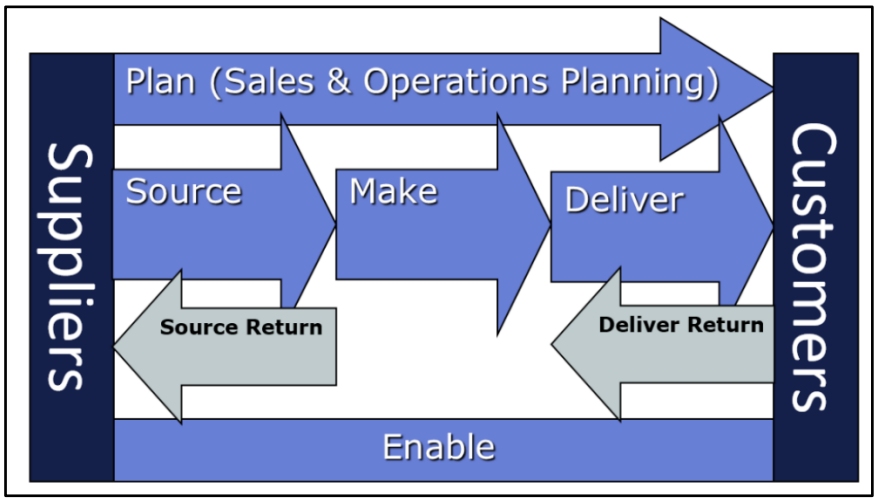

Figure 2. SCOR Model, The Supply Chain Operations Reference Model Level 1 Processes (Arden Eric, 2020).

The SCOR model (Figure 2) is built around six major management processes: Plan, Source, Make, Deliver, Return, and Enable.

Plan process involves the development of a set of metrics to monitor the supply chain so that it is efficient, cost-effective, and delivers high quality and value to customers. Planning activities include demand and supply planning, inventory planning, and production scheduling.

Source process focuses on the procurement practices required to obtain goods and services to meet planned or actual demand. Source processes cover the management of inventory, ordering processes, supplier selection, and the management of goods received.

Make process involves the production activities necessary to convert raw materials into finished goods. This process includes scheduling, packaging, staging, and managing production.

Deliver process entails all the order management steps from processing customer inquiries and quotes to the transportation of goods and managing delivery logistics. It includes order management, warehousing, and the distribution of products to customers.

Return process deals with the reverse flow of goods in the supply chain for returns, repairs, or recycling. It involves returning defective products and supports post-delivery customer support.

Finally, enable process supports the other five process blocks by managing information and financial flows throughout the supply chain. Enable processes include facilities management, IT services management, quality control, compliance, and human resources.

Performance Attribute	Definition
Reliability	The ability to perform tasks as expected. Reliability focuses on the predictability of the outcome of a process. Typical metrics for the reliability attribute include: On-time, the right quantity, the right quality.
Responsiveness	The speed at which tasks are performed. The speed at which a supply chain provides products to the customer. Examples include cycle-time metrics.
Agility	The ability to respond to external influences, the ability to respond to marketplace changes to gain or maintain competitive advantage. SCOR® Agility metrics include Flexibility and Adaptability.
Cost	The cost of operating the supply chain processes. This includes labor costs, material costs, management and transportation costs. A typical cost metric is Total Supply Chain Costs.
Assets	The ability to efficiently utilize assets. Asset management strategies in a supply chain include inventory reduction and in-sourcing vs. outsourcing. Metrics include: Inventory days of supply and asset utilization.

Figure 3. The SCOR performance attributes (ASCM, 2020).

To assess the effectiveness of supply chain operations on top level SCOR model highlights 5 main performance attributes (Figure 3). These attributes represent the most critical functions that a supply chain must fulfil to support overarching business objectives (ASCM, 2020).

While all five goals outlined in Figure 3 are significant, it is essential to emphasize the foremost goal, Reliability. Reliability is critical as it ensures the consistent delivery of products or services to customers. The significance of supply chain management transcends mere operational efficiency; it is pivotal for sustaining customer satisfaction and loyalty. In an era marked by exceedingly high consumer expectations, the capability to deliver the right products at the right time and in pristine condition is crucial for maintaining a strong brand reputation. Companies must try hard to achieve this goal.

2.2.2 Modern challenges and trends in SCM

Today's supply chain management (SCM) has grown increasingly complex, navigating a myriad of challenges posed by a rapidly changing global landscape. The following trends are developed in 2024 by The Association for Supply Chain Management (ASCM) is the global leader in supply chain organizational transformation, innovation, and leadership (ASCM, 2024).

First trend is digitalization of supply chains. Converting data from physical to digital formats enables technologies like IoT, AI, blockchain, and cloud solutions. Supply chain organizations increasingly develop their networks into connected and intelligent digital ecosystems. Some will pursue complete digital trans-formations, while others will gradually integrate automation that reduce repetitive tasks, allowing employees to focus on tasks where humans excel over machines (ASCM, 2024).

Second trend is steep increase in utilization of big data and analytics. Supply chain analytics help organizations identify inefficiencies, enhance customer service, and improve resilience. By standardizing data exchanges—from optimizing freight routes to using sensor data for maintenance—companies can better manage operations and reduce costs. Effective data sharing is crucial to maximizing these benefits (ASCM, 2024).

Next trend is wide adoption of AI. AI is transforming key aspects of supply chain management, from intelligent sourcing and logistics to assembly safety with robotics and augmented reality for training. Machine learning, a core part of AI, is automating complex decisions in areas like demand forecasting and product development, streamlining operations significantly (ASCM, 2024).

Trend number four is the continuation of investment in systems and people. The adoption of supply chain technology escalates at considerable rates. Simultaneously, ongoing investments in

employee training and development on the latest technologies are fostering a culture of innovation (ASCM, 2024).

Next trend revolves around the drive and adoption of tools aimed at enhancing visibility, traceability, and location intelligence. Supply chain visibility and traceability allow organizations to monitor goods from origin to destination, providing stakeholders with near-real-time data on orders, inventory, and potential disruptions. Additionally, location intelligence offers insights into network status, while AI and machine learning enhance predictions of future conditions using historical data on delays, traffic, weather, and bottlenecks (ASCM, 2024).

The trend of disruption and risk management has surfaced, drawing considerable attention. Supply chain disruptions have become routine due to issues like infrastructure congestion, geopolitical changes, natural disasters, and material shortages. Organizations are shifting from reactive to proactive management by continuously preparing for disruptions. This involves assessing risks, developing mitigation strategies like diversifying suppliers and increasing inventory, testing plans to refine them, communicating with stakeholders, and regularly updating these plans to maintain their effectiveness (ASCM, 2024).

Agility and resilience have become indispensable in contemporary times. Today's consumer-driven market demands a more agile supply chain equipped with tools like flexible machines, collaborative robots, and smart packaging. A skilled workforce adept in technology will be key to adapting quickly to changes. Enhancing resilience through digitization, optimization, sustainability, and talent development is a critical strategic for the future (ASCM, 2024).

The next significant trend is the movement towards green and circular supply chains. Many supply chain organizations are aiming for carbon neutrality and net-zero waste and water goals, driven by increasing external pressures to enhance sustainability across their operations through partner collaboration, advanced technology, employee education, clear targets, and transparent reporting (ASCM, 2024).

Cybersecurity has emerged as a critical topic in recent years. Modern global supply chains face widespread cyber threats, necessitating robust cybersecurity measures to prevent data breaches, delays, reputational damage, and financial losses, with professionals needing to stay informed and invest in risk-based security solutions and training (ASCM, 2024).

Finally, Geopolitics and the deglobalization of supply chains hugely affect modern supply chains. Geopolitical conflicts, security concerns, and climate change mitigation will continue to disrupt global supply chains, prompting a shift to-wards regional, simpler networks (ASCM, 2024).

In summary, achieving SCM goals is challenging as it requires maintaining a constant state of adaptability to effectively address ongoing changes. Modern technology serves as a vital and potentially effective tool in navigating these complexities.

2.2.3 Hype cycle for supply chain strategy

Given the vast array of modern technologies available, obtaining expert advice is crucial for making informed decisions. The well-known company Gartner provides this guidance through its 2023 Hype Cycle for Supply Chain Strategy (Tohamy Noha, 2023). This model (Figure 4) helps supply chain leaders to identify and prioritize investments in critical capabilities, detailing each one's maturity, adoption level, and impact. The cycle tracks technologies from their innovation-triggered introduction, through the Peak of Inflated Expectations and the Trough of Disillusionment to their eventual broader adoption and consistent performance.

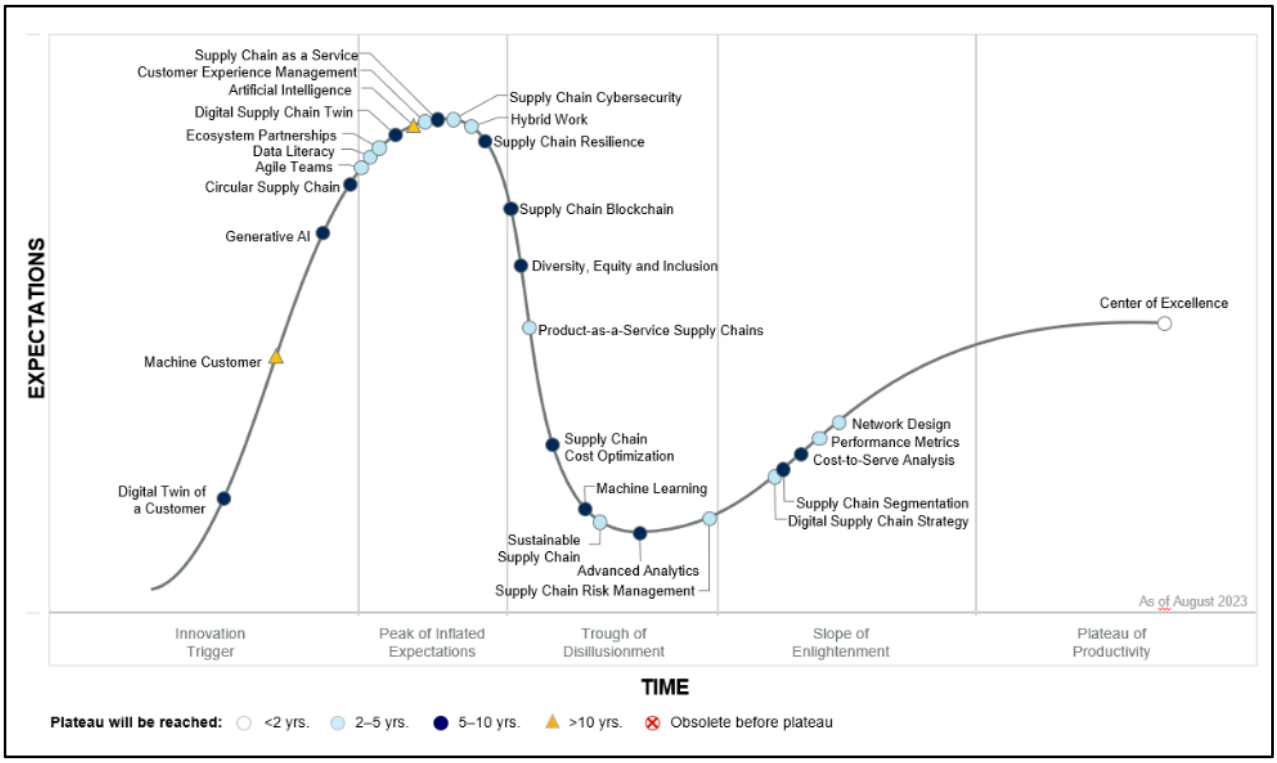

Figure 4. Gartner Hype Cycle for Supply Chain Strategy 2023 (Tohamy Noha, 2023).

A noteworthy observation from the 2023 cycle is the position of AI at the peak of Inflated Expectations (Tohamy Noha, 2023). This indicates that while AI is currently receiving a great deal of attention and optimism, it is expected to face challenges and scepticism in the short term. However, Gartner predicts that AI will reach a plateau of productivity in over a decade, suggesting a transformative impact on supply chain strategies in the long run. This trajectory underscores the need for leaders to manage expectations around AI and prepare for its gradual integration into their

supply chain processes, ensuring readiness for its mature phase of consistent productivity and benefits.

2.2.4 Future vision of SCM

Many experts predict a significant transformation in SCM, fuelled by the integration of diverse technologies. Digital technologies are expected to play a leading role, driving innovations and efficiencies that reshape traditional supply chain models. This evolution is anticipated to leverage advancements in artificial intelligence, real-time data analytics, and automation, fundamentally altering how supply chains operate globally (Aarasse & Idelhakkar, 2023, pp. 53–54).

The concept of Supply Chain 4.0 has emerged as a response to contemporary challenges and technological opportunities. Aligned with the Industry 4.0 trend, Supply Chain 4.0 extends these principles into the realm of SCM. In the following section, a brief introduction to Supply Chain 4.0, will be provided (Figure 5).

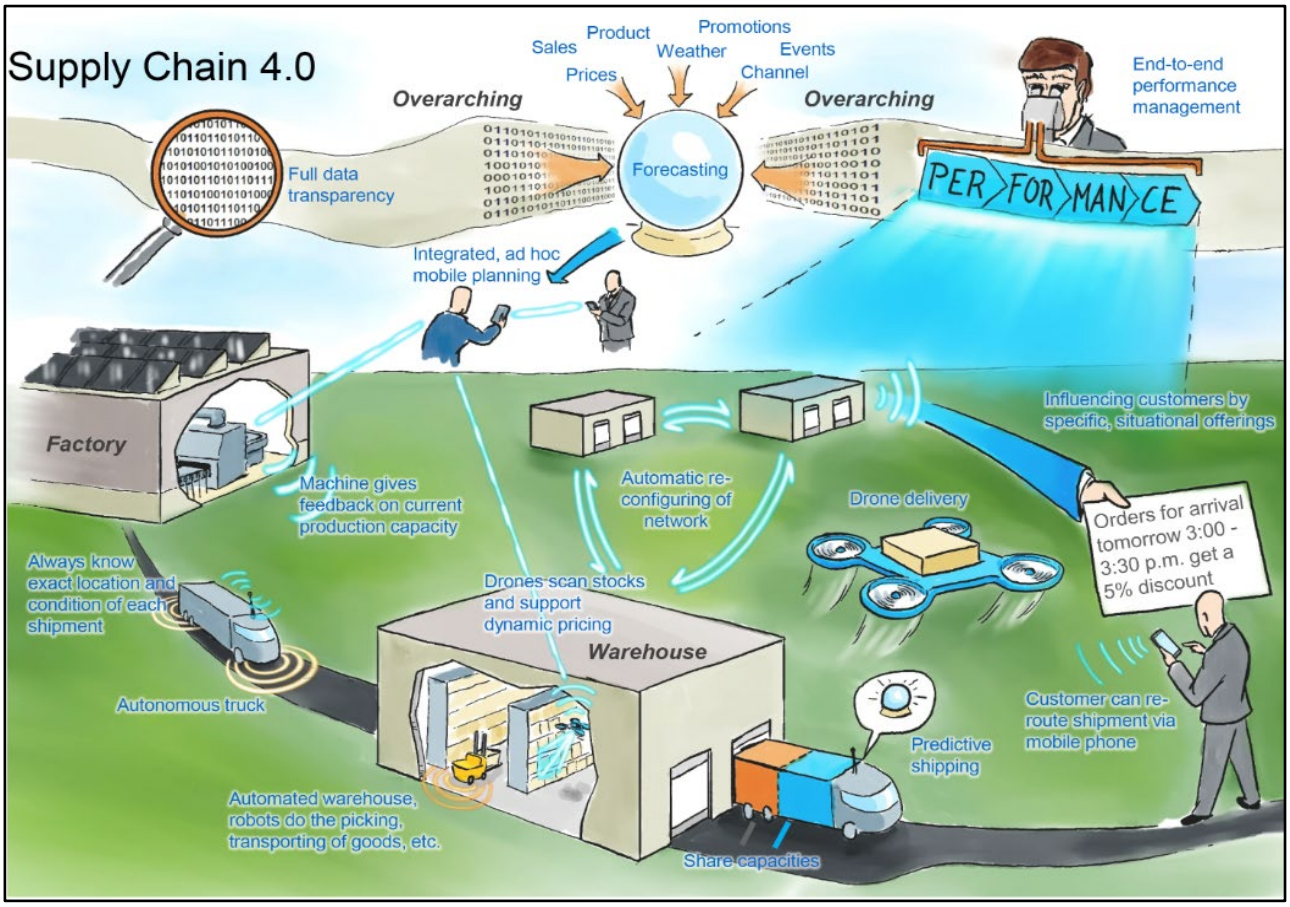

Figure 5. Supply Chain 4.0 (Alicke et al., 2016).

“Supply Chain 4.0 - the application of the Internet of Things, the use of advanced robotics, and the application of advanced analytics of big data in supply chain management: place sensors in every-

thing, create networks everywhere, automate anything, and analyse everything to significantly improve performance and customer satisfaction" (Alicke et al., 2016, p. 1).

The main idea of Supply chain 4.0 in comparison with current supply chain is to cope with the new changed requirements using enhanced digitalization. Digitization brings a Supply Chain 4.0, which will be faster, more flexible, more granular, more accurate, more efficient.

Digitalization increases the speed in SCM. New distribution methods enable faster delivery times, with advanced forecasting techniques, including predictive analytics of internal and external data, allowing for precise weekly and even daily demand forecasts, paving the way for innovations like "predictive shipping," as seen in Amazon's patented system, where products are shipped before orders are placed and matched with existing logistics network shipments for expedited delivery to customers (Alicke et al., 2016, p. 2).

The flexibility SCM is significantly enhanced by the introduction of digital tools. The integration of ad hoc and real-time planning, minimizing planning cycles and allowing continuous dynamic reactions to changing demand or supply circumstances, alongside enhanced flexibility in delivery processes enabling customers to reroute shipments as needed, underscores a more adaptable and responsive supply chain framework.

Additionally, digitalization significantly enhances granularity across various SCM processes. The rising demand for individualized products is driving micro segmentation and mass customization, leading to the management of customers in more granular clusters and the offering of a diverse range of tailored products through multiple "logistics menus," ensuring customers find options that precisely match their needs.

Another benefit of digital technology is its ability to enhance accuracy in SCM. The implementation of next-generation performance management systems offers real-time, end-to-end transparency in the supply chain, providing synthesized top-level KPIs (Key Performance Indicator) and granular process data, facilitating informed decision-making across all levels and functions through integration in a "supply chain cloud" shared among stakeholders.

Finally, digitalization substantially boosts efficiency. Supply chain efficiency is enhanced through the automation of physical tasks and planning, with robots managing material handling processes from receiving to shipping, autonomous trucks facilitating product transportation, and cross-company transport optimization improving truck utilization and transport flexibility, while ongoing network optimization ensures alignment with business needs.

To conceptualize the future of SCM, a blueprint is provided in the subsequent paragraphs, outlining the key components that will drive developments. (Alicke et al., 2016, pp. 5–7).

Future supply chain planning will heavily leverage big data, advanced analytics, and knowledge work automation, notably through levers such as "predictive analytics in demand planning" and "closed-loop planning." Predictive analytics in demand planning employs machine learning to analyse internal and external variables, leading to significant improvements in forecast accuracy and the adoption of probability distributions for demand volume, enabling targeted discussions and advanced inventory management. Closed-loop planning integrates demand and supply planning into a flexible, continuous process, adjusting safety stocks based on expected demand distributions and dynamically adapting pricing decisions to optimize profit and minimize inventories.

Logistics is undergoing a profound transformation driven by connectivity, analytics, additive manufacturing, and advanced automation, notably witnessed in the increasing autonomy of vehicles and the disruptive impact of 3-D printing on warehousing and inventory management strategies. The integration of next-generation user interfaces, like optical head-mounted displays, facilitates seamless machine integration in warehousing operations, while advancements in robotics and exoskeletons enhance warehouse productivity, paving the way for holistic automation processes. The adoption of autonomous vehicles promises significant cost reductions in transportation and product handling, with applications ranging from controlled environments to warehouse operations.

Order management is enhanced through no-touch order processing, which automates the ordering process from intake to confirmation by integrating systems, applying stringent order rules, and maintaining updated master data, resulting in lower costs, higher reliability, and improved customer experience. Real-time replanning facilitates instantaneous adjustments to pro-duction schedules and replenishment, ensuring an up-to-date and reliable planning base that enables additional customer services, such as faster lead times, enhancing transparency and customer satisfaction.

Performance management is undergoing significant change, with real-time access to granular data from internal and external sources enabling a shift from periodic to operational processes focused on exception handling and continuous improvement, supported by automated root cause analyses that identify underlying issues and trigger appropriate countermeasures, streamlining decision-making and enhancing overall efficiency.

Looking further into the future, experts anticipate the emergence of Supply Chain 5.0, which will evolve into self-thinking supply chains. District feature of Supply Chain 5.0 will be mass personalization of products and services. This advanced stage introduces intelligent robots and systems, significantly impacting supply chains. The core features of SC 5.0 include collaborative human-

robot interactions, tailored customization for consumers, and integration with Society 5.0's smart societal infrastructures. The concept of a self-thinking supply chain assumes extensive IoT connectivity with seamless integration of cyber-physical system. This system handles vast data volumes in real time, enabling proactive risk management and continuous performance monitoring within the supply chain (Hangl et al., 2022, p. 2).

In summary, contemporary SCM faces numerous challenges, and the road ahead is anticipated to be equally demanding. Addressing these challenges necessitates leveraging key enablers, particularly various technological advancements like AI. The following section will provide a detailed review of AI applications in SCM.

2.3 Artificial Intelligence in supply chain management

This sub-chapter completes the theoretical background by reviewing literature on the application of AI in SCM. It begins by explaining the role, value, and benefits of AI in SCM, illustrating how AI technologies enhance SCM processes. The discussion proceeds by outlining AI technologies used in SCM. Then, the text reviews the challenges commonly experienced during the implementation of AI, providing an understanding of the barriers to effective integration. The chapter concludes by considering ethical considerations, emphasizing the importance of ethical guidelines and responsible AI usage in SCM contexts. This sub-chapter serves as a comprehensive overview, presenting the complex dynamics of AI applications in SCM.

2.3.1 AI's role in SCM: value, benefits, and applications

AI has become increasingly significant in the field of SCM in recent years. Undoubtedly, AI has demonstrated immense worth to companies and is widely regarded as a pivotal technology for Industry 4.0. Its popularity stems from its capacity to enhance the responsiveness of SCM processes to the diverse challenges prevalent in the modern world, including unforeseen disruptions, dynamic customer expectations, fierce global competition, the growing imperative to digitise companies, and ever-evolving technological advancements (Cannas et al., 2023, p. 1).

Cannas et al. (Cannas et al., 2023, pp. 3–9) conducted a comprehensive literature review on the applications and benefits of AI (Figure 6).

SCOR Process	Area of SCM where AI is applied	Benefits
Plan	• Demand forecasting and planning • Inventory management	• Growth of inventory turnover index • Reduction of the number of days out of stock • Optimal inventory control
Source	• Supplier selection • Quality control of incoming orders	• Increase of the accuracy and decrease of the computation time for supplier selection • High accuracy in defects identification
Make	• Scheduling • Manufacturing Quality • Maintenance	• Optimisations of resources usage • Improved early fault detection • Improved maintenance service
Deliver	• Stocking • Process inquiry and quote • Shipping • Picking • Logistics optimisation	• Reduction of offer planning time • Effective communication with the customer • Increase in offers acceptance • Increase in customer satisfaction • Reduction of transportation
Return	• Network design • Optimisation of collection activities • Optimisation of warehousing • Processing selection	• Reduction of inventory carrying costs • Reduction of location costs • Improvement of customer service • Automation and speed up of returns sorting • Increased environmental sustainability

Figure 6. Summary of the literature review on AI applications and benefits. Adopted from (Cannas et al., 2023, pp. 8–9).

To provide further insight, the subsequent sections include examples demonstrating how AI is applied in SCM and the benefits it provides.

In the plan process of SCM the literature review focuses on such areas of SCM as demand forecasting, demand planning, and inventory management. The key aspect is forecasting accuracy, which is essential for ensuring the effectiveness of management decisions. Traditional methods often struggle to achieve high accuracy due to inherent complexities in data patterns and external factors affecting demand variability. Machine learning (ML) methods are revealed to be used by companies to overcome these challenges. The benefits derived from ML methods are the reduction of forecast error and days of coverage, growth of the inventory turnover index, and reduction in the number of days out of stock (Cannas et al., 2023, p. 8).

In examining the source process within SCM, it is evident that AI is applied, yielding significant benefits. Supplier selection and verification of incoming order quality are areas of SCM where AI is found to bring benefits. AI is utilized to process the vague information about supplier attributes and to balance the goals of cost-effectiveness and reliability. Quality verification in supply chains increasingly leverages AI and machine learning techniques across all stages of quality control. For instance, a study highlighted the effectiveness of a visual recognition system capable of identifying and classifying textile defects with an accuracy rate of 97.8% (Cannas et al., 2023, p. 8).

Additionally, in the make process, AI is successfully used for production scheduling with results surpassing human levels. The same AI technology used to enhance quality inspections of incoming materials is also effectively utilized during the manufacturing process to promptly detect defects, allowing for early intervention and correction. Machine learning has proven to be highly effective in predictive maintenance, achieving remarkable accuracy levels that significantly enhance maintenance processes and ex-tend equipment lifespan (Cannas et al., 2023, p. 8).

In the delivery process, AI is employed in multiple applications. One example is process inquiry and quotation pro-cess, where Natural Language Processing (NLP) is used in chatbots to respond to general client inquiries with potential to even automate direct sales. Another example is AI being utilised through the process of data mining to improve shipping operations by optimising delivery methods. This approach significantly reduces distribution costs, speeds up delivery, and maintains a high customer satisfaction rate of 98.75% (Cannas et al., 2023, p. 9).

Finally, within the return process, AI contributes to advancing the circular economy, particularly through its application in reverse logistics. Reverse logistics pose greater complexity compared to forward logistics due to uncertainties like return volumes, quality, and timing. The literature highlights AI's effectiveness in circular economy and reverse logistics, offering more quantitative and robust solutions compared to other methods (Cannas et al., 2023, p. 9).

To summarise, the use of AI into supply chain management highlights its profound impact on various aspects, such as prediction, supplier choice, scheduling of production, and reverse logistics. By utilising AI technologies like machine learning to enhance the accuracy of forecasting and employing data analytics to identify the best suppliers, SCM solutions not only minimise prediction mistakes and improve quality verification, but also increase production efficiency and simplify return pro-cesses. As a result, these innovations result in substantial cost reductions and increased customer satisfaction.

2.3.2 AI technologies used in SCM applications

Several AI technologies significantly enhance supply chain management operations. Although these applications typically integrate multiple AI techniques, this section discusses each technology separately for clarity, helping to better understand their individual contributions to supply chain management (Nandi et al., 2023, pp. 7–20).

Machine Learning (ML) is a type of automated analytical modelling that allows a system to continuously improve its performance by learning from data. It identifies patterns and makes decisions with minimal or no human intervention. The successful use cases in SCM were found in demand planning, quality prediction, customer churn prediction, customer purchase prediction and many others. This technique is now one of the most prevalent AI applications in supply chain management (Nandi et al., 2023, p. 12).

Artificial Neural Networks (ANN) are often linked with deep learning. ANN excel in identifying patterns and deriving insights from large historical datasets across various industries. With their complex, multilayered architectures ANNs are particularly effective in supply chain functions where traditional rule-setting is challenging, despite the availability of extensive data. ANN proved to be effective in SCM, particularly in areas such as supplier evaluation, cycle time estimations, quality inspection, manufacturing data analysis, route planning and others (Nandi et al., 2023, p. 8).

Expert Systems (ES) simulates solutions for specific complex problems by iteratively leveraging past experiences and human expert knowledge. This includes useful facts, relationships, and heuristic rules to effectively search for solutions. Areas of application of ES in SCM include product maintenance and troubleshooting, warehouse operations management, programming of industrial robots, inventory management, supplier evaluation (Nandi et al., 2023, p. 10).

Genetic Algorithms (GA) iteratively solve complex problems through search and optimization, using adaptive search heuristics. Renowned for swiftly finding satisfactory solutions, GA proves valuable in various SCM domains, including warehouse optimization, network planning, assembly line balancing, supplier evaluation, demand forecasting (Nandi et al., 2023, p. 14).

Fuzzy Logic (FL) techniques formalize and solve uncertain real-world problems by introducing degrees of acceptance and denial. Widely used in SCM, FL clarifies complex systems with unclear cause-effect relationships, offering useful approximations rather than exact solutions, quickly and effectively. Areas of SCM for FL application encompass customer satisfaction assessment, logistic centre location planning, evaluation of logistics operations, automated guided vehicle navigation for material transport, lot size determination (Nandi et al., 2023, p. 18).

Natural Language Processing (NLP) is a branch of artificial intelligence focused on under-standing and processing human language. NLP in SCM automates text analysis for tasks like sentiment analysis, document summarization, and information extraction from various sources. It im-proves forecasting, customer service, procurement, and inventory management (Aslam & Calghan, 2023, pp. 211–218).

Computer Vision (CV) in SCM automates visual analysis tasks, enabling systems to continuously improve performance by learning from images. It identifies patterns and makes decisions with mini-mal or no human involvement. Successful applications include inspection and quality control, as-sembly, transportation, and disassembly (Zhou et al., 2023, p. 1). CV is now one of the most prev-alent AI applications in supply chain management, offering enhanced efficiency and accuracy in visual-based tasks.

Robotics is a branch of engineering and science that involves the design, construction, operation, and use of robots. Robots are programmable machines capable of carrying out tasks autono-mously or semi-autonomously, often in place of or in collaboration with humans. Robotics in SCM automates physical tasks, enabling systems to continuously improve performance through learning and adaptation. Successful applications include warehouse automation, picking and packing, in-ventory management, and transportation (Azadeh et al., 2019).

2.3.3 Challenges in AI implementation within SCM

AI enhances supply chain management, but integrating it is difficult. Organisations face data com-plexity, quality challenges, and the requirement for experienced staff and robust technology infra-structure. To alter SCM operations using AI technology, careful planning and resource allocation are needed.

Numerous comprehensive literature reviews have been conducted on this topic, each offering valu-able insights. These reviews serve as critical resources, synthesizing existing research and high-lighting trends, and opportunities in the literature. This aggregation of scholarly work not only deep-ens our understanding but also guides future research directions in the field. One such review (Cannas et al., 2023, pp. 2–10)provides a thorough summary of the challenges encountered when implementing AI in the SCM domain (Figure 7).

#	Category	Challenges / Barriers
1	Financial	• High investment needed, insufficient financial resources • Lack of clarity on the economic benefit, • Lack of risk management tools to decide the amount of investments
2	Organisational	• Shortage of workforce with adequate skillset • Lack of internal digital culture & training for technological projects • Lack of employees' readiness and high resistance to change • Low integration and collaboration among organisation departments
3	Strategical	• Difficult process changes and ineffective change management • Lack of strategical roadmap, poor focus on Industry 4.0 adoption • Lack of top management commitment • Lack of lean production practices • Lack of stakeholders' involvement and engagement
4	Technological	• Lack of digital IT infrastructure, poor provision of connectivity • Integration issues like compatibility, scalability and interoperability between machines, equipment, technologies, and network systems • Low maturity level of the desired technology • Resistance to share data due to lack of information security • Challenges in ensuring data quality

Figure 7. Size of companies of interview respondents. Adopted from (Cannas et al., 2023, p. 10).

The subsequent paragraphs will systematically review each challenge category, providing examples to enhance understanding. Figure 7 serves as a summarizing source of information.

First category of challenges refers to financial issues. Companies may struggle to fund initial AI technology investments including software development, hardware infrastructure, and data management systems. Competition for qualified AI and SCM professionals raises compensation and recruitment costs. To promote sustainable adoption and maximise return on investment, financial planning and strategic decision-making must balance AI-driven efficiencies' long-term benefits with immediate financial restrictions (Cannas et al., 2023, p. 10).

The next set of challenges, which complicate matters, are of an organizational nature. Lack of skilled staff and cultural resistance slow down effective AI implementation. Additional challenges stem from internal deficiencies in digital readiness and poor cross-departmental collaboration, impeding the smooth functioning and utilization of AI-driven solutions within organizations (Cannas et al., 2023, p. 10).

Other obstacles encountered are attributed to strategic challenges. The absence of a strategic roadmap and weak commitment from top management often lead to resource misallocation and insufficient support for AI projects. Addition-ally, the lack of lean production practices and inadequate stakeholder engagement may further negatively affect AI implementation (Cannas et al., 2023, p. 10).

The next category of challenges is technological. Among all the challenges listed in Table 7, one of the most prevalent is the issue of data quality. AI algorithms require vast amounts of clean, high-quality data for training and testing purposes. However, SCM data is often fragmented, inconsistent, and prone to errors. Addition-ally, legacy systems may not be designed to capture the breadth and depth of data needed for AI applications. Therefore, organizations must invest in data collection, cleansing, and integration efforts to ensure the reliability and accuracy of AI-driven insights (Cannas et al., 2023, p. 10).

Finally, legal challenges also emerge. Adoption of AI is slowed down due to insufficient regulations on cybercrime and data theft, and a lack of standardized government guidelines for AI use. This regulatory gap in-creases legal risks and complicates compliance, making it crucial for companies to navigate these issues carefully to secure and ethically use AI (Cannas et al., 2023, p. 10).

2.3.4 Ethical considerations

The integration of artificial intelligence (AI) into supply chain management offers substantial benefits, but it also raises important ethical considerations. As companies utilise AI tools to optimise operations and enhance decision-making, it is crucial to carefully evaluate the ethical factors (Ahmed, 2023, p. 1520) such as data privacy, algorithmic bias, transparency, human-machine collaboration and environmental impact.

AI relies heavily on personal data from partners, suppliers, and customers. To safeguard this data, organisations must implement privacy and security procedures. Risk mitigation requires transparent data governance, encryption, and secure data storage.

Data biases can impair AI systems and their output. This bias may affect supply chain management price, supplier selection, and resource allocation. Firms must identify and eliminate algorithmic biases to promote justice and equality.

Since AI systems are often "black boxes," it is hard to under-stand their decisions. Supply chain management must ensure transparency and explanation for important decisions. Businesses should establish AI systems that detail their decision-making pro-cess to build confidence and responsibility.

AI in supply chain management should improve human talents, not replace them. Workplaces should encourage AI-human collaboration. Effective training, re-skilling, and job redesign can ensure that AI technologies complement human skills rather than displace jobs.

AI-enabled supply chain management should include social and environmental implications. For instance, cost-based transportation route optimisation may ignore sustainability. Organisations should use AI to make decisions based on ethical ideals like carbon reduction and fair labour.

3 Research methodology

This chapter describes the methodologies and techniques used to gather and analyse data. It includes the design of the study, population and sample description, data collection methods, and data analysis.

3.1 Methodology

The study addresses research questions by integrating findings from the literature review with direct empirical observations using a case study methodology.

The subject of AI is widely discussed, yet there remains a notable scarcity of empirical studies on the topic. This highlights the suitability of qualitative research methodology, characterized by its exploratory nature, as suitable approach (Jabbour et al., 2015). Unlike quantitative methods which focus on numerical and generalizable data, qualitative methods allow for a more detailed exploration of the subjective experiences and perceptions of individuals within organizations (Dehalwar et al., 2023, pp. 9–12). The qualitative approach is selected for its ability to offer comprehensive insights of the phenomena. The study will aim to capture the opinions and viewpoints of SCM professionals on the current applications of AI in SCM and on the future possibilities. An additional rationale for employing qualitative methods is the precedent set by prior researchers who investigated similar topics using qualitative approaches. For instance, Cannes utilized similar methods in their research (Cannas et al., 2023).

Case study method is very suited for several reasons. First, case studies offer practical insights that facilitate both understanding of the topic and guidance for its real-world application (Ellram, 1996). Finally, extensive utilization of the case study method in supply chain research is well known and frequently used (Ramanathan et al., 2017).

Incorporating multiple cases within a case study strategy enables the examination of whether insights drawn from one case are reproducible across others, thereby facilitating broader generalizations. It is proposed that employing multiple case studies may offer greater benefits compared to a single case study, underscoring the importance of a robust rationale for selecting a single case study design (Saunders et al., 2009, p. 140). Therefore, qualitative research through multiple case studies is adopted as a best-fit technique.

3.2 Research design

The research is structured into three main phases (Figure 8). The initial phase begins with the development of a theoretical framework, which is crucial for setting the research direction. This

framework is established based on a comprehensive literature review that identifies and organizes the main themes associated with AI applications in SCM. These themes are essential for defining a focused research agenda.

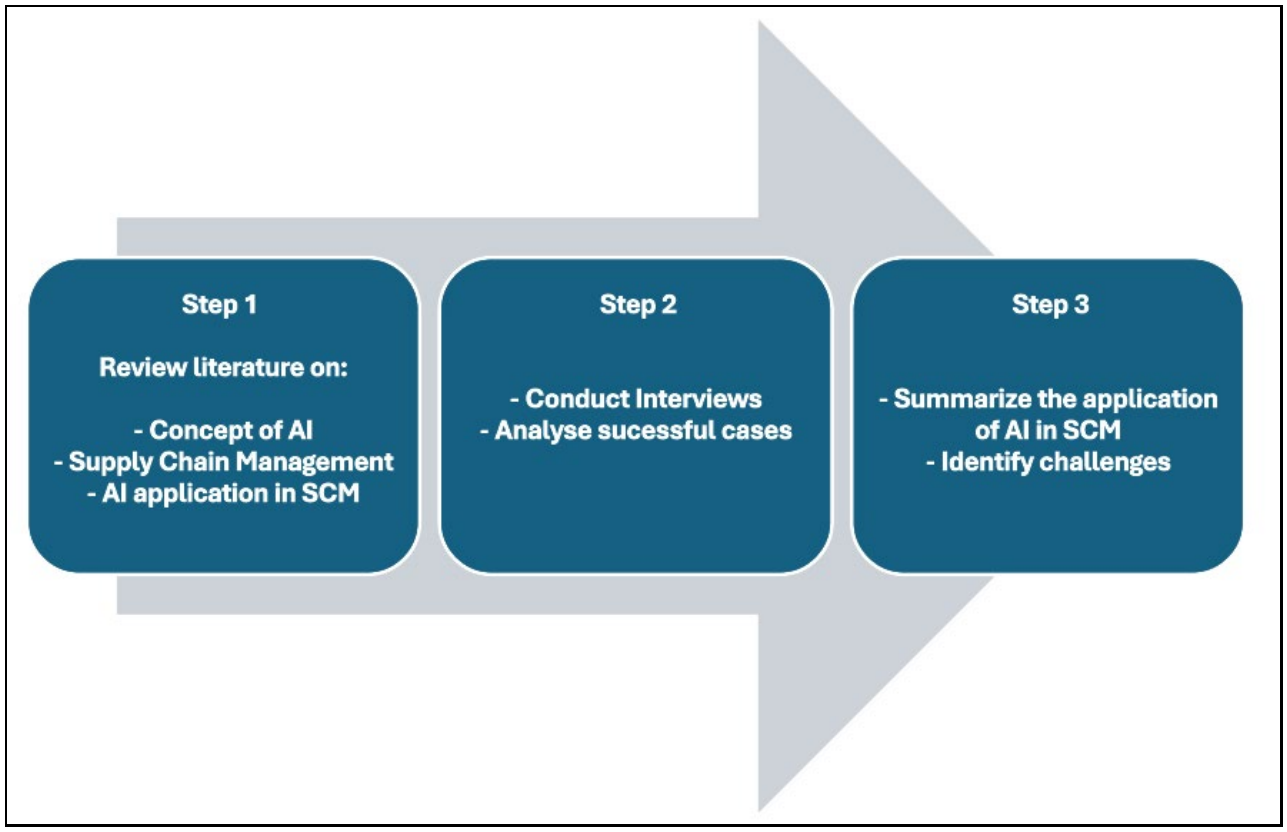

Figure 8. The approach of exploratory research.

Following the creation of the theoretical framework, it serves as a foundation to derive discussion points for interviews. This preparation ensures that the interviews are aligned with the research objectives, making the data collection process more efficient and targeted. Data gathering is conducted through semi-structured interviews with industry professionals and experts in SCM and AI. This phase is vital for obtaining practical insights and understanding the real-world application, value, benefits, and challenges of AI in SCM.

The final part of the research involves a qualitative analysis of the interview data, which helps to evaluate the impact and effectiveness of AI technologies within SCM settings. This study employs a methodology of multiple case studies, enhancing the external validity of the results by gathering data from various cases.

There are several scope considerations to keep the study focused. From geographic perspective, the research will focus on European market and USA as these regions are advanced in terms of adoption of AI technologies. Speaking about the technological scope, the study will concentrate on

specific AI technologies used in SCM. This includes, but not limited to, machine learning algorithms, predictive analytics, automation, and robotics. There will be no industry specific limitations. Also, there will be no restrictions on the company size. Finally, the scope of the work will not include sophisticated theories, methods, processes, and techniques of AI and SCM. Rather the attempt will be to keep things simple and focus on what is the most important.

The study aims to analyse the AI solutions implemented by companies to support SCM and to gain insights into the benefits and challenges of AI in this context. Given the potential presence of multiple AI applications within companies, the study focuses on the AI application as the unit of analysis. Six companies were selected with employing AI in a total of 26 areas within SCM.

3.3 Data collection and analysis

Data collection utilized two primary methods: semi-structured interviews for gathering primary data and reviewing and analysing digitally available interviews related to the research topic for secondary data. This approach involved analysing transcribed content from existing interviews with SCM professionals on digital media platforms, facilitating comprehensive data gathering through both direct engagement and existing digital resources.

The semi-structured interview, guided by predetermined subject directions, enables the researcher to delve deeply into discoveries. It provides flexibility to explore topics in-depth while maintaining the study's focus (Mashuri et al., 2022, p. 24).

In this study, participants were AI experts directly engaged in or accountable for AI projects within their company, possessing comprehensive awareness of current situations and challenges. All interviews were transcribed for analysis.

The primary objective of the interviews was to explore how AI applications can enhance supply chain management (SCM). To achieve this, questions were crafted based on the theoretical framework of the thesis, aiming to assess the interviewees' understanding and knowledge of the value, benefits, and challenges associated with AI in SCM. Appendix 1 details the questions asked and explains how they contribute to the research.

3.4 Validity and reliability

This study seeks to enhance the validity and reliability of its analysis through multiple approaches.

To ensure reliability, a standardized protocol was adhered to throughout the data collection process (see Appendix 1). To establish construct validity, empirical evidence was triangulated from diverse sources such as case companies' websites, internal documents concerning AI projects,

and data from AI providers, thereby securing a robust base of evidence. Furthermore, all interviews were recorded, and verbatim transcripts were compiled into a case-specific database for each instance examined.

Internal validity was established by iteratively comparing the analysis results with existing literature until theoretical saturation was achieved. To improve external validity and enhance the generalizability of the findings, the multiple case study method was employed. This approach facilitated data collection from various cases, allowing to underscore the similarities and differences among the cases.

4 Results and analysis

This chapter presents the empirical findings of the research. It opens with a review of the practicalities of data collection procedures. This is followed by the presentation of the results obtained, accompanied by preliminary analyses. Information will be presented using tables and graphs to enhance understanding. A more extensive analysis and interpretation of these results are reserved for the subsequent chapter.

4.1 Practicalities of data collection

Six companies with experience of AI application in SCM took part in the research and 1 company provider of SCM software with AI (Figure 9). The companies were chosen based on the external communications and publicly available information on SCM practices and technologies.

Company ID	Size	Industry	Country	Respondents Role	AI solution source	Time (min)	Date
A	Big	Technology	UK	Supply Chain Transformation Leader (P1)	Self-Developed	90	29-Mar-24
B	Big	Automotive parts and accessories	USA	VP of Replenishment (P2)	Specialized SCM Software	30	6-Apr-23
C	Big	Pet care market	Finland	Group CIO (P3)	Specialized SCM Software	32	3-Mar-23
D	Big	Technology	Finland	Product Director (P4)	Specialized SCM Software	33	7-Mar-23
E	Big	Foodservice provider	UK	Head of Inventory (P5)	ERP	3	1-Nov-23
F	Big	Management consulting	USA	Senior Data Scientist (P6)	Self-Developed	25	7-Apr-24
G	Small	Automotive manufacturing	Germany	Managing Director (P7)	AI Company Collaboration& ERP	3	16-May-23

Figure 9. Details on the companies participating in the study and about the interviews.

The data collection for this study was carried out from March 10 to April 10, 2024, using two primary methods. Primary data was collected by conducting semi-structured interviews. The secondary data was obtained with review and analysis of digitally available interviews related to the

research topic. This approach involved analysing transcribed content from existing interviews with SCM professionals, sourced from digital media platforms. This dual approach allowed for comprehensive data gathering from both direct engagement and existing resources on digital media platforms.

From a geographical perspective, the interview sample is quite diverse, including participants from countries such as the USA, Germany, the UK, and Finland. Additionally, the sample is varied and rich from an industry standpoint, encompassing sectors like manufacturing, retail, technology, and management consulting.

Semi-structured interviews with Companies A and F were conducted using Microsoft Teams, utilizing its transcription function to record the discussions. Companies B, C, D, E, and G were selected from digital online interviews. The criteria for selecting these online interviews focused on discussions about the application of AI in supply chain management (SCM) from a customer perspective, with interviewees being SCM professionals who possess relevant experience. Notably, one interview with Company D involved an AI software provider. While this interview provided valuable insights, it is not included in the statistical analysis in the "Results of the Research Section" because the primary focus was on gathering insights from customer companies about AI adoption. Consequently, the tables in the next sub-chapter 4.2 report data from six interviews, not seven.

4.2 Research results

Q1: Could you share the size of your company? Would you classify it as small, medium, or large?

Most respondents, comprising 83%, are employed in large-scale companies (Figure 10). Only one company in the sample represents a small firm; however, it is worth noting that this company functions as a subsidiary of a larger corporation. Consequently, it is plausible that the decision-making process regarding AI adoption within this subsidiary was influenced by its parent company.

This observation serves as a solid illustration of the prevailing trend wherein smaller and medium-sized enterprises (SMEs) tend to lag in the adoption of AI technologies. This difference might be because AI is seen as expensive, complicated, and needing a high level of digital maturity to use. It looks like given the comparatively greater resources at their disposal; large corporations find it easier to embark on the journey of AI adoption.

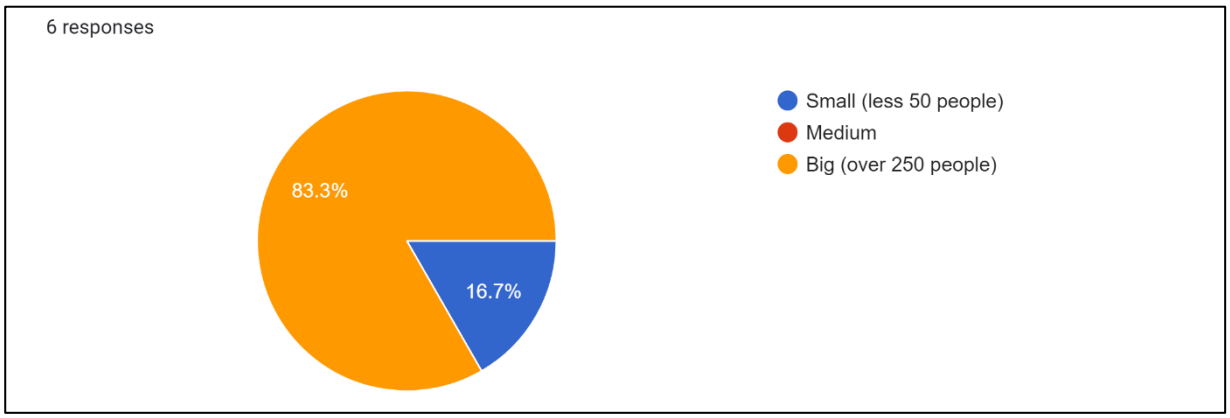

Figure 10. Size of companies of interview respondents.

Considering the substantial benefits that AI offers within SCM, it is imperative for SMEs to investigate and capitalize on these opportunities. Moreover, governmental support may be required in facilitating the adoption of AI technologies among SMEs. Moreover, conducting focused research on this topic could help to better understand and improve the situation.

Q2: For how many years has your company been using AI in supply chain management?

Respondents' responses are evenly divided into three categories: 2 years, 3 years, and 5 or more years (Figure 11). This provides an intriguing insight into the journey of AI adoption undertaken by the companies.

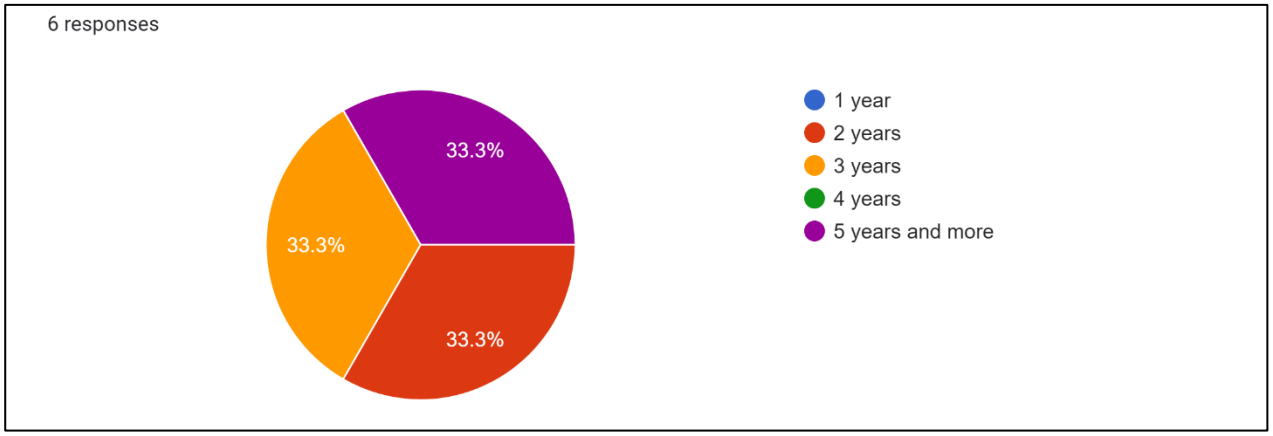

Figure 11. Number of years the respondent companies using AI in SCM.

We observe that some companies have been using AI for a considerable period, reflecting extensive experience. They have progressed beyond the initial stages of adoption and have transitioned to using AI as a regular part of their operations. At the same time, most respondents are newcomers to AI adoption, having utilized it for 2-3 years. They are still in the process of adjusting to this

transition phase, learning to utilize AI in various aspects of their operations, and integrating it into their business processes.

Additionally, it is evident that all necessary components for implementing AI within a company are readily accessible. The acquisition of AI capabilities does not require a "magic wand"; rather, with dedication, investments, and focused effort, any company can embark on the journey of integrating AI into its SCM operations.

In summary, our sample indicates that despite AI's invisible nature, it has already been integrated into the operations of our respondent companies for some time. Therefore, the future of AI is already present, and it is gradually becoming an indispensable component of everyday operations for companies, their employees, products, customers, and partners.

Q3: How would you describe the extent of AI usage in SCM in your company?

50 % of respondents perceive their AI usage in SCM to be at an “Intermediate” stage of development (Figure 12, Figure 13). 33 % of respondents have described their AI usage in SCM as "Established," indicating that they consider AI to be well-integrated and firmly established. Finally, the smallest portion 17 % think they are at “Developing” stage, suggesting that they are quite new in the domain and focusing on learning and adopting to changes.

#	Level of AI use	Description
1	Exploratory	On initial stages. Basic tools, small scale.
2	Developing	Progressing, some tools & seeing benefits.
3	Intermediate	Multiple AI solutions, tangible benefits.
4	Established	Wide range of advanced AI tools, excellent value.
5	Advanced	Sophisticated AI in all areas at a large scale.

Figure 12. Description of AI use / implementation levels.

It is worth noting that none of the responses indicated either the most basic "Exploratory" or the most advanced "Advanced" levels. This suggests that the companies within our sample are positioned within the intermediate range of AI capabilities growth, indicating significant potential for future development.

Finally, this data may provide insights into the level of AI adoption and maturity within the companies as perceived by respondents.

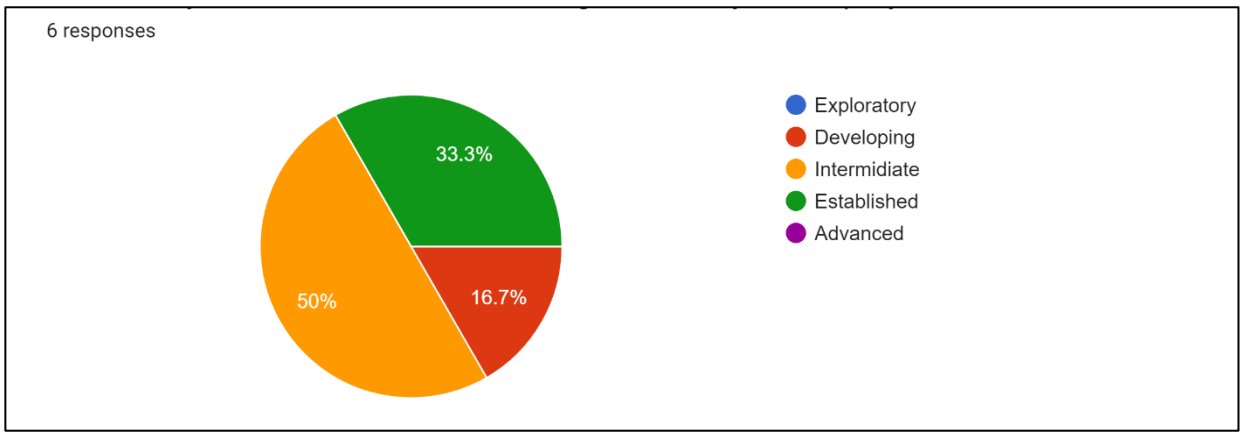

Figure 13. The level of AI usage in SCM in respondent companies.

Q4: Could you elaborate on how the AI capabilities for SCM were developed or acquired by your company?

There is a notable variety in the companies approaches to acquiring AI capabilities for SCM. Six respondents used nine methods (Figure 14). Four methods were most popular with two use cases each. First one is using AI which is embedded within large Enterprise Resource Planning (ERP) systems. The second method entails utilizing AI features integrated into specialized SCM software. Additionally, companies demonstrated a preference for developing AI capabilities in-house, which is a third popular method. Lastly, one unique case involved the acquisition of AI through collaboration with an external AI technology company to develop a computer vision AI application. Available AI acquisition sources are listed in Figure 15.

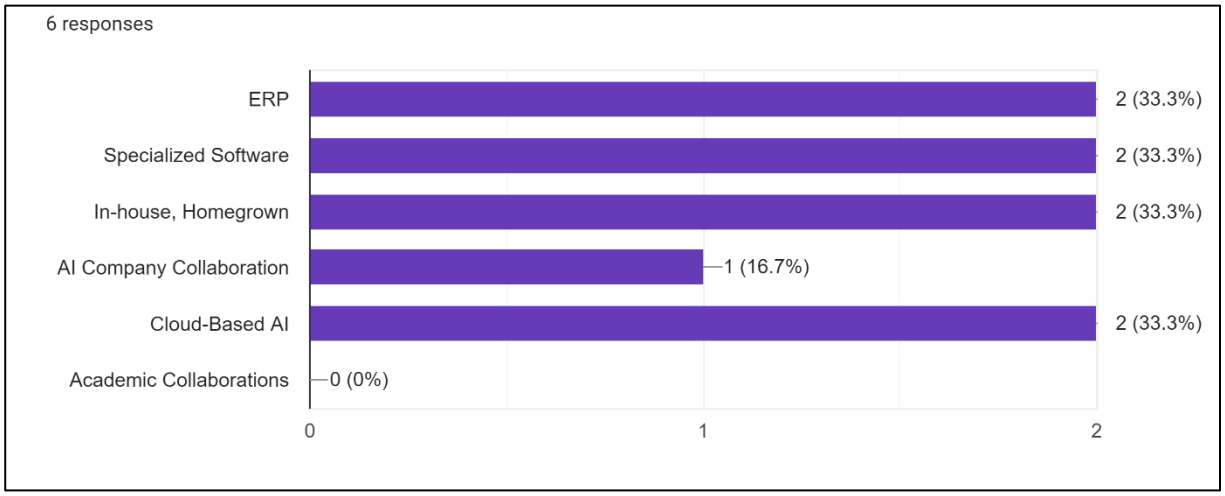

Figure 14. Approaches to acquiring AI capabilities employed by companies.

These findings highlight the diverse ways companies follow in acquiring AI capabilities for SCM. This may indicate that companies have different strategic priorities or varying levels of access to resources and expertise. Some companies prefer to prioritize in-house development to have more control and customization. Others choose to engage in collaboration or opt for specialized available solutions to leverage external expertise.

P1 illustrates the process for AI development in-house with internal resources:

> P1" The development of AI model is done as follows. We as a SCM department initiate the project. We prepare a business where with clear descriptions why we need AI model, what problems it will solve and what benefits it will bring. The business case gets approval with the management team. Next, a cross-functional team is formed with Data Scientist from IT department and with analyst from SCM side. This team makes the analysis what data is available, what functionality the model to have, what are the inputs to the Model, what are outputs. Then the AI model is trained with lots of historical data. We monitor the predictive power of the model and adjust until we see that AI model starts to predict at the satisfactory level. Once the performance of the AI model is good it goes from testing phase to production phase. It starts working in real life."

#	AI Acquisition Sources	Description
1	ERP	AI built-in Enterprise Resource Planning Software: SAP, Oracle, Microsoft Dynamics 365
2	Specialized Software	Specialized SCM Software with AI: Relex Solutions, Blue Yonder, etc.
3	In-house, Homegrown	In-house Homegrown AI: developed with internal resources
4	AI Companies Collaboration	Collaboration with AI Tech Companies / Service providers / Consultants
5	Cloud-Based AI	Cloud-Based AI: Using AWS, Google Cloud, Azure, which offer AI as a Service
6	Academic Collaborations	Academic / Government Agencies Partnerships and Collaborations

Figure 15. AI Acquisition Sources available for companies.

One could argue that the findings indicate a significant demand for AI solutions in SCM, as evidenced by companies actively engaging in AI acquisition. On one hand, companies have the option to develop AI internally, while on the other hand, there is plenty of market offerings for AI solutions available. Therefore, there are no strict limitations on AI acquisition, allowing companies the freedom to start the AI journey any time.

Q5: In which areas of supply chain management has your company applied AI?

To start, AI is utilized across a wide array of areas, with the six respondent companies employing AI in a total of 26 areas within SCM (Figure 16). On average, each company applies AI in four SCM domains. Considering that some respondent companies are new to using AI, this shows the rapid pace at which AI is spreading into the SCM territory. This notable outcome underscores AI's adaptability to business tasks and its considerable potential for further expansion.

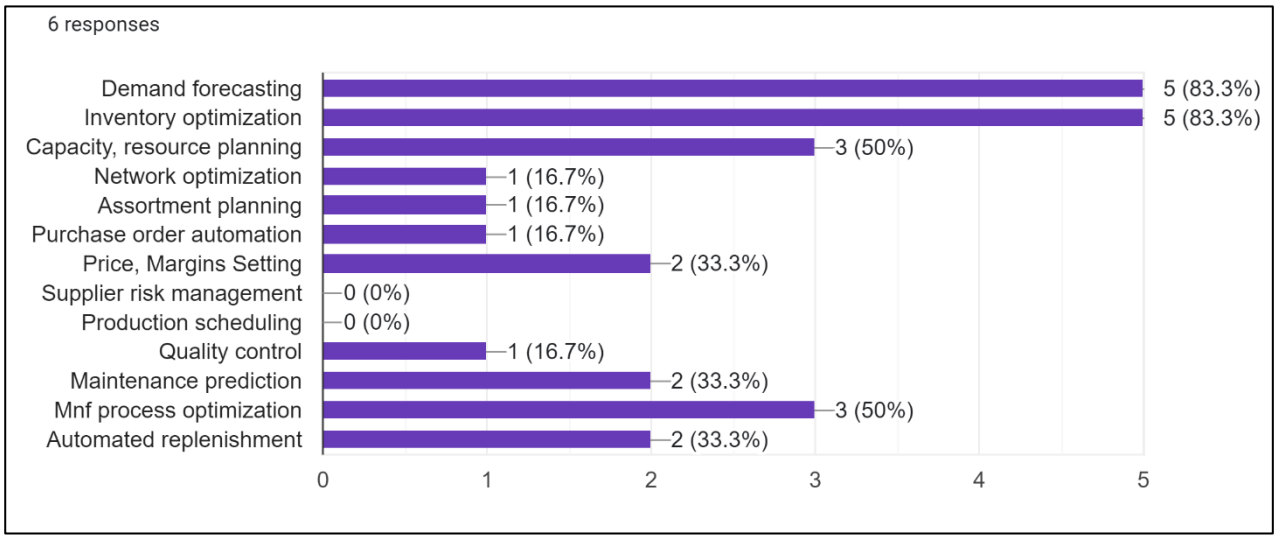

Figure 16. Areas of the supply chain where AI is implemented by companies.

Next, there is a noticeable diversity in the Supply Chain Management (SCM) processes where companies utilize AI, with a total of 12 areas mentioned. This highlights the versatility and effectiveness of AI as a tool, demonstrating its ability to provide support across a wide array of SCM functions.

Furthermore, from the research data it is evident that AI is applied across all domains of SCM, including planning, logistics, manufacturing, and procurement. For instance, in manufacturing, respondents cited applications such as maintenance prediction, quality control, and manufacturing process optimization. This illustrates AI's capacity to improve every aspect of SCM, prompting companies to consider its implementation.

The two leading areas consistently mentioned by all companies except one were "Demand forecasting" and "Inventory management." This trend may stem from their critical importance within SCM, where significant value is derived. For instance, accurate demand forecasting directly influences manufacturing, procurement, and logistics operations. By improving demand forecasts, companies naturally enhance downstream activities related to manufacturing, procurement, and logistics. As for the inventory management, it is indispensable in SCM as it is essential for meeting customer demand and has a significant impact on cost optimization. The findings indicate that companies, being highly business-oriented and practical, strategically invest in AI in areas where they can derive the most benefit from its implementation.

P2 shares insights on the abilities of AI to enhance forecasting and replenishment:

> P2: “First is enhanced forecasting and replenishment. Today, we use the new system across all our distribution centres. Now planners have ability to be more proactive and much more collaborative with merchandisers and our suppliers as they work on the forecast together. Especially important that now planners have the new tools and all the data together in one place. So that has been a big win for us.”

P1 illustrates the effectiveness of AI in predictive maintenance tasks with an example:

> P1: “AI models are fast, accurate and make SCM process highly effective and efficient. I will give you a simple example. We have a substantial number of items for predictive maintenance planning. We need to consider lots of factors and planning task is quite hard as the planning horizon is long with an incredibly detailed granularity level. For a human to do the planning job it will take exceptionally long time and it may contain errors. AI model does it extremely fast with prediction accuracy of 91 % which is remarkably high. So, this is simple explanation why we adopted AI in our SCM department.”

P7 discusses how AI contributes to ensuring quality control to secure excellent product quality:

> P7: “Employees on the line must detect every defect. We have an AI inspection algorithm which is monitoring the whole operation. First pilot project was about checking the glue application. The AI model looked at the product using a camera and checked if all glue bits are there and in the right position. First results were ready after 4 hours. After about 48 hours the model was so accurate that we knew we could trust it blindly. We would like to push this AI model further and establish and scale it much more widely at our plant. It is a huge added value for the customers and for us as a manufacturing company as well.”

In summary, the research highlights broad and extensive AI adoption across all areas of SCM, indicating AI's impressive adaptability and promising potential for further growth.

Q6: What specific AI technologies your company uses, such as machine learning, optimization algorithms, NLP, other?

Research reveals that six companies are using 16 AI technologies, on average almost three AI technology per one company (Figure 17). This considerable number highlights the popularity of various AI technologies in addressing SCM challenges, despite the relative novelty of AI. Moreover, it suggests that companies are customizing their AI strategies to suit their specific SCM needs, leveraging on a wide range of AI techniques.

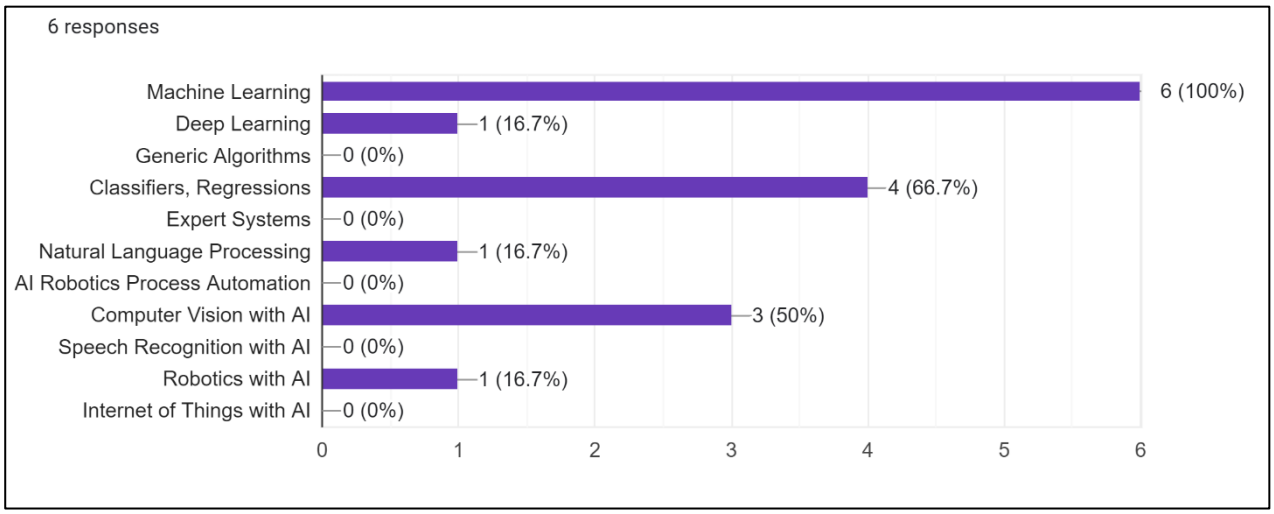

Figure 17. AI technologies employed by companies.

Among all AI technologies, Machine Learning (100 %), Classifiers, and Regressions (67 %) are the most frequently used AI technologies among respondent companies. This could be at-tributed to the exceptional suitability of these tools for addressing critical SCM tasks in demand forecasting and inventory management. These tools excel in predictive modelling, pattern recognition, and data classification, making them particularly effective in optimizing these areas of supply chain operations.

It is interesting to note that newer AI technologies like NLP, Deep Learning and Robotics are making their way in the SCM domain. This suggests that the pace of AI technology adoption is accelerating, and we can anticipate several additional AI technologies entering the SCM field very soon.

Q6: What are the benefits your company has experienced from using AI in supply chain management?

Research reveals a broad range of benefits from AI implementation in SCM. On average, companies report nine distinct advantages from using AI. Another key finding is the wide range of benefits, with 15 different advantages identified. This variety and volume of benefits demonstrate AI's

critical role as an effective tool in SCM, justifying the investment and effort required for its integration (Figure 18).

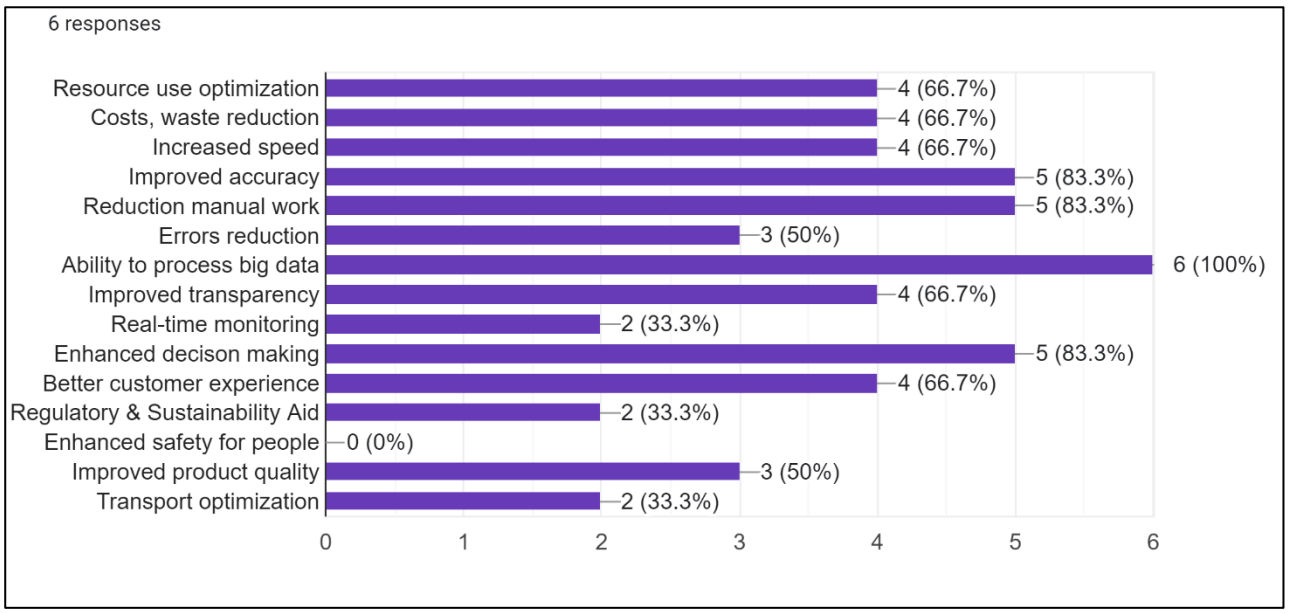

Figure 18. Benefits of employing AI in SCM.

Most Recognized Benefit is the “Ability to Process Big Data” (100%) which is mentioned by all companies. This capability serves as the foundation for additional benefits like "Real-time Monitoring" (33%) and "Improved Transparency" (66%), each adding further advantages to SCM. Discovering these benefits in research results come is hardly surprising. In the digital age, where data is continuously generated at an unprecedented rate, the capacity of AI to process big data might soon become not just a competitive advantage but a necessity for survival and success in SCM. AI enables SCM to be more agile, responsive, and customer-focused significantly contributing to the organization's business objectives.

P4: “We have now much more visibility with new system for our management team. All the inventory, forecasting and ordering activities are easily viewed with different filters and aggregation levels. We have learned so much over the last 2 years. We really managed to use the new system and utilise its tools to improve our team's effectiveness in the planning.”

Given that AI is a type of computer program, it natural to see in the research findings benefits such as "Increased speed" (67%), "Improved accuracy" (83%), and "Error reduction" (50%). The significance of these benefits cannot be overstated for digital and lean supply chains, as they directly enhance operational efficiency, minimize waste, and optimize performance across the network.

P1 offers an illustrative example and shares his perspective on the topic:

> P1: “The reason for AI / ML introduction is it makes life easier. Before when it was done by people, the level of planning quality was poor. At that time, it was considered normal, and all lived with such a low level of planning. Now the quality of planning by AI model is much better. The speed, quality and accuracy are much better with AI model.”

Artificial Intelligence (AI) accomplish various tasks autonomously, thus releasing time for individuals. This is evidenced by research findings indicating a benefit "Reduction in manual work (83%)". This automation represents opportunities for workers to focus on value-added activities.

Achieving cost efficiency remains a central objective within SCM, with organizations focused on refining processes and lowering expenses. Research highlights the significant benefits provided by AI, demonstrated with such benefits as "Costs and Wastage Reduction" (67%) and "Resource Use Optimization" (67%).

P5 shares the experience and highlights multiple benefits of incorporating AI within the company:

> P5: “We are introducing smart systems to make effective digital supply chains. This demand planning app will help the business make right decisions that will lower wastage, avoid unnecessary deliveries. It gives us the opportunity to combine multiple sources of data into one system. It just speeds up our ability to be able to make those fact-based decisions very quickly. It allows us to step back from what were emotionally driven human instinct decisions and just know that the decision we are making is ... is bang on. This app was perfect. It can provide us with the tools to almost tell us what we need to do and make the teams life simpler and therefore improve the service that we give to our consumers.”

AI in SCM offers more benefits, including "Better Customer Experience" (67%), "Improved Product Quality" (50%), "Transport Optimization" (33%), and “Regulatory and Sustainability Aid” (33%). This broad range highlights the significant potential of artificial intelligence (AI) to support various aspects of Supply Chain Management (SCM) through a wide array of tasks.

Q7: What challenges, if any, has your company faced while integrating or using AI in supply chain management?

Embarking on the journey of AI adoption is not without challenges for companies.

Research indicates that respondents encountered significant technical challenges, with "Data quality and availability" (67%) being the most prevalent issue (Figure 19). This was followed by "Integration issues" (33%) and "Issues with IT infrastructure" (33%). These challenges are interrelated, stemming from a historical lack of emphasis on IT infrastructure, data collection, and master data management in the pre-digital era. The shift towards digitalization and the adoption of AI technologies have highlighted these gaps. Therefore, it is logical for such issues to emerge when

companies attempt to implement AI for the first time, highlighting the need for a robust digital foundation to effectively leverage AI capabilities.

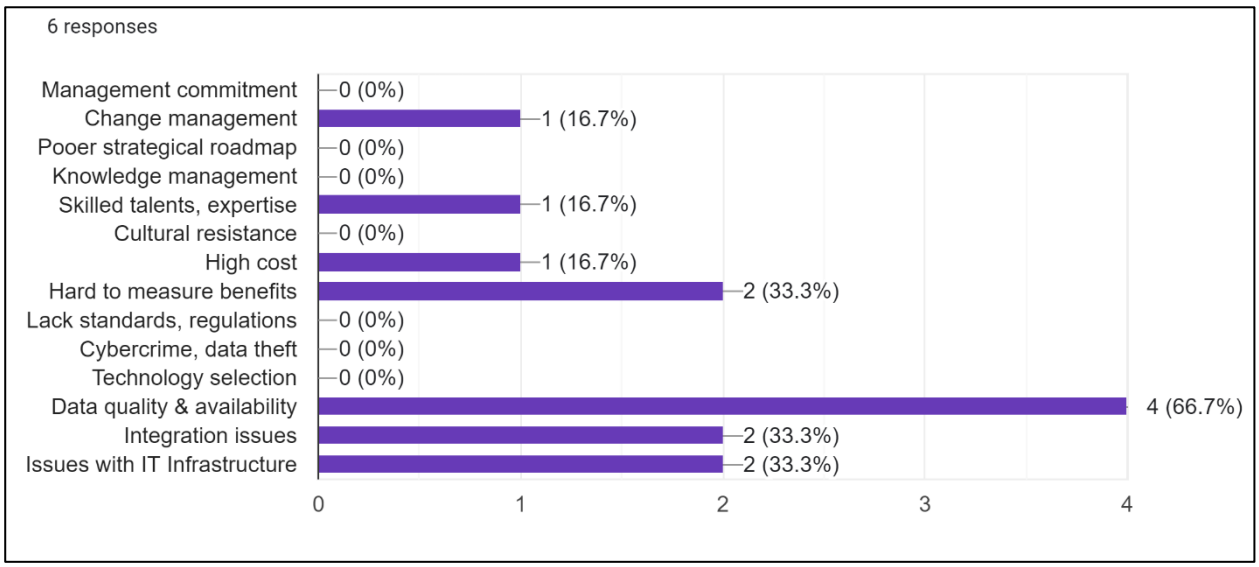

Figure 19. Challenges encountered during AI implementation and use.

P1 and P4 stressed the importance of data quality in building an effective AI model:

> P1: “The most challenging challenge by far is data. The availability of historical data and its quality and continuity. It is ideal if there are no “time breaks” in the historical data. In our company data structure constantly changes and it becomes a challenge when training AI models. We had 1 such issue and we spent lot of time and put lots of efforts to validate past data and align it to one format”.

> P4: “First is the data quality. It sounds trivial but, in our case, it was not trivial at all. Initially we did not have good data quality and we are still working to improve that. One insight we got is that if you have good data, it pays off in many different areas later and visa-versa.”

The next most frequently cited challenge is the difficulty in measuring the benefits of AI (33%), which may be merely coincidental. This challenge has become particularly visible for some companies that started their AI integration during the COVID-19 pandemic, a period marked by significant economic turbulence. Under such conditions, establishing a stable baseline for assessing the benefits of AI is challenging, given the fluctuating economic environment. Nonetheless, for all companies, it is advisable to establish a clear business case and define success criteria at the outset of any AI project implementation.

P1 shares further issues encountered:

> P1: “Another challenge was to make a calculation of benefits and present it to the management team. They were asking questions like what the value of benefits in monetary form. And that was difficult to calculate. So, we were highly creative and put lots of effort to make meaningful and convincing benefits calculation.”

Other challenges highlighted include "Change Management" (17%), which points to issues connect-ed to adopting new ways of working with AI. Additionally, there is the issue of "Lack of Skilled Tal-ents and Expertise" (17%), referring to the shortage of AI experts, which complicates AI adoption. Finally, "High Costs" (17%) underlines the significant investments required to acquire AI-powered solutions.

It is interesting to note that the challenges emerge during the phase of AI implementation within a company. Once the AI system is integrated and the transition towards a new operational method is completed, challenges seem to shrink significantly. This insight reveals that the most demanding period is the initial adoption of AI and the shift towards a new way of working, after which the process typically becomes much smoother.

> P1: “Do we have issues after AI implementation? No. We implemented model 1 year ago and now it is producing stable and reliably results, so it is easy now. We got adapted to new process. Data is flowing to the AI model smoothly. We have some fine-tuning ideas in the pipeline, but these are minor things. We need to remember that AI model can do planning job only for those items that are inside the model and whenever something new appears we need to make sure it gets included in the AI model.”

Q8: How do you envision the use of AI in supply chain management in general by the year 2030?

Expectations for the future integration of AI in Supply Chain Management are optimistic or very optimistic (Figure 20, Figure 21).

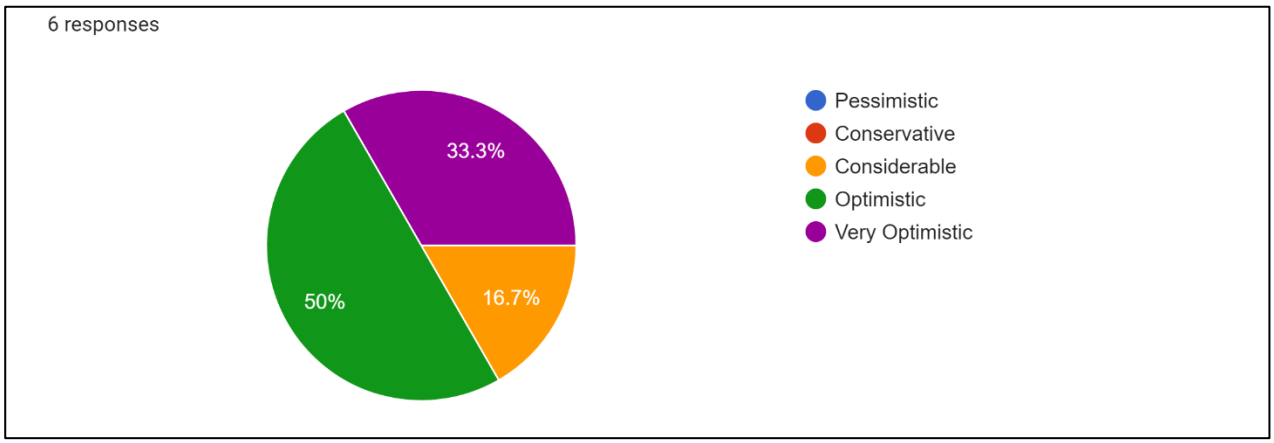

Figure 20. Viewpoints on the adoption of AI by the year 2030.

50% of respondents are optimistic, predicting that AI will perform half of all SCM tasks by 2030. Another 33% are very optimistic, suggesting that the majority of SCM tasks will be AI-driven by 2030. Meanwhile, 17% anticipate considerable AI use, with AI taking over approximately 30% of SCM tasks. Notably, no respondents held pessimistic or conservative views. This consensus highlights the immense potential for future AI integration in SCM and indicates an irreversible trend towards significant AI adoption. With such a considerable portion of tasks expected to be automated within the next 6 years, urgent discussions on employment implications are required. This necessitates a comprehensive research and proactive dialogue among institutions like labour un-ions, governments, and the broader society to address potential impacts on employment levels.

#	2030 viewpoint	Description
1	Pessimistic	Minimal AI integration expected (AI will execute ~ 5 % of tasks in SCM)
2	Conservative	Limited AI adoption (AI will execute ~ 5-20 % of tasks in SCM)
3	Considerable	Advanced level anticipated (AI will execute ~ 20-40 % of tasks in SCM)
4	Optimistic	Expected wide use, big impact. (AI execute ~ 40-60 % of tasks in SCM)
5	Very Optimistic	AI will revolutionize SCM (AI will execute ~ 60-80 % of tasks in SCM)

Figure 21. Description of viewpoints on AI use / implementation levels in 2030.

P1 and P4 provided their insights on the roadmap for AI adoption in Supply Chain Management (SCM):

> P1: “I think development of AI in general and in SCM specifically follows Gartner hype model. To me AI now is at the height of inflated expectations. I think it will fall with disillusionment and then AI will reach a productivity plateau. How soon usage of AI will become a common practice in SCM? Hard to say but I think in 5 years' time is more likely than in 10 years' time from now. I think the growth will not be linear as it relates to technology development. I think it will be slow for some time, but then it will start to grow very fast at some point in time. Regarding the share of tasks that AI will take over from people by 2030, I think it will be around 30 %. I think not more because there are some head winds for that. Master data needs to be cleaned and people are needed for that, paper transactions are needed, need for human communication will still be relevant. In my vision AI will be a great helper, something like Excel nowadays”.

> P4: “AI and Machine Learning are here to stay. It is not going away and will be at the forefront of retail tech advancements. Not just in retail, but in wholesale, distribution centres and in manufacturing as well. We are at the start of AI journey. We do not know how it is going to look like in 3-5 years as these things are developing almost overnight. So, it is a very exciting place to be.”

P1 highlighted the crucial aspect of skillset evolution in SCM resulting from the integration of AI technologies:

> P1: “What is important is the nature of work will change and it will require new skill sets from workers. It will be needed for people in SCM to understand basics of AI, how AI model works at least in terms of inputs and outputs. It will be necessary for people to understand how the model is programmed, so that to make most use from the interactions between AI model and a human. For example, nowadays for ChatGPT there are popular lists of prompts which contain information how to best ask a question to ChatGPT. So, it will be very important for people to know how to formulate a good question to the AI model to get a good answer. I think this will be a key skill for people. Not so much a skill of programming as it will remain for Data Scientists. It will be like nowadays there is a wise man who made Excel, but most people use Excel with great value without deeply understanding the back-office work mechanics.”

P1 shared an interesting perspective on the potential risks associated with job displacement due to the integration of AI technology:

> P1: “Will AI adoption will lead to fewer people employed? Most probably - yes. But I think it will have an interesting pattern. I think that initially companies will see a solid potential in AI and may lay off too many people. Companies will give too many tasks to AI. But soon after when AI will face the reality which is very unstructured, when AI will have to deal with imperfect Master Data, when AI will need to manage a new promotion that has a unique behaviour on the market, then it will be the time AI will run into big problems. It will make lots of mistakes and companies will return people back to work. Humans will be needed as some kind of glue that ties things together. Humans will be needed to make difficult decisions and be accountable for these decisions. Overall employment levels in SCM may decrease but some people will remain at work. People will need to communicate with each other. I do not see machines fully communicating with other and making lots of complex decisions, at least in the time frame of 3-5 years.”

5 Discussion

This chapter offers a comprehensive discussion of the findings presented in the previous chapter. Initially, it provides a detailed interpretation of the obtained results, delivering answers to the research questions. This is followed by a critical comparison with prior studies and the theoretical framework established earlier, showing similarities or discrepancies. Subsequently, the chapter explores the broader implications of these findings, discussing their theoretical, practical, and policy dimensions.

5.1 RQ1. AI application in supply chain management, value and benefits

Throughout history, technology has been a catalyst for economic growth, starting with the Industrial Revolution and extending to the present digital era, with Artificial Intelligence (AI) emerging as a compelling technological breakthrough. AI is fundamentally reshaping Supply Chain Management, helping companies to streamline operations, minimize costs, and boost efficiency. AI successfully assists companies in addressing a wide range of supply chain management challenges.

Companies highlight AI's capacity to optimize the use of resources and significantly reduce costs and waste. One example is predictive maintenance AI models, which streamline maintenance schedules. This allows for the avoidance of overtime, urgent repairs, and underutilized workforce, ultimately leading to cost savings. In today's highly competitive business environment, achieving cost efficiency and resource optimization in SCM is not just an advantage—it's a necessity. Therefore, such AI-driven capabilities are very important, as they directly contribute to core businesses goals.

Research confirms AI applications in SCM are highly valued for enhancing operational efficiency and boosting accuracy. Example is AI-enabled SCM software that enables more accurate demand forecasting and automatic replenishment, leading to optimized inventory levels. This directly and positively affects working capital levels and costs. In today's unpredictable environment, characterized by rapid shifts in consumer preferences and unexpected events such as COVID-19 and the semiconductor crisis, fluctuations in demand and supply disruptions are increasingly common. In such situations, speed and accuracy are crucial. By utilizing artificial intelligence technologies in SCM, companies can quickly and accurately respond to changes in demand. This capability allows businesses to remain agile and competitive, effectively adapting to the dynamic conditions of the market.

The study shows that by automating manual tasks, AI helps frees up human workers to focus on more complex, value-added activities. A good illustration is Automatic ordering and replenishment

by AI powered software that is saving lots of employee time. Automation will be increasingly crucial in the future, especially as new technologies such as the Internet of Things, NLP, Computer Vision, blockchain, and robotics become fully matured and adopted. It will be essential for SCM to leverage AI to integrate these technologies effectively. AI will play a key role in data analysis, communication, and decision-making processes.

The respondent companies acknowledge AI's capacity to process and analyse large volumes of data, significantly aiding in decision-making processes. For example, AI models are very effective in enhancing decision-making in retail by performing complex calculations for modelling trade-offs between price levels, margins, and volumes. This advanced computational ability allows retailers to optimize pricing strategies and improve profitability.

Research demonstrates AI enhances supply chain transparency, providing clearer visibility over operations. An excellent example is AI-powered ERP systems for demand forecasting that enable different levels of data aggregation, improving visualization and transparency. This leads to better decision-making, better forecast quality, improved product availability, and a superior customer experience which is vital in to-day's competitive business environment.

The study found AI is beneficial in regulatory compliance and helps to improve product quality. AI-powered computer vision is highly effective in enhancing quality compliance and defect detection, as demonstrated by one of our companies. By increasing quality AI-powered solutions support sustainability by reducing waste and decreasing the environmental impact of businesses. In the context of today's challenge of climate change, this approach proves to be highly relevant.

Finally, companies recognize the role of AI in enhancing transport optimization and enabling real-time monitoring capabilities. For example, AI-powered software optimizes replenishment decisions, enabling smooth transportation from distribution centres to retail stores. This enhances efficiency as deliveries are optimized and it contributes to sustainability by minimizing energy use and reducing emissions.

The study’s findings were consistent with most other research surveys conducted by the reputed consulting experts– Gartner, PwC, Harvard Business Review and others. Gartner's survey revealed that organizations leveraging AI/ML to automate and optimize processes involving supply chain data typically outperform their competitors and demonstrate high operational efficiency (Gartner, 2024). The survey “PwC’s 2024 Digital Trends in Operations Survey” conducted among 600 operations and supply chain professionals highlights the benefits of adopting AI in organizations, such as cost reduction, improving speed and accuracy of decision-making, increasing resilience (PwC, 2024). The article "How Global Companies Use AI to Prevent Supply Chain Disruptions"

from Harvard Business Review discusses how leading companies leverage AI to enhance the resilience of their supply chains (Van Hoek Remko & Lacity Mary, 2023).

Research findings have multiple implications that can be slitted in 3 dimensions: theoretical, practical, and policy. From theoretical viewpoint, the use of AI invites a rethinking of well-established SCM models like the SCOR model, integrating technology more deeply into each element of plan, source, make, deliver, and return. Theoretical frameworks must now consider the algorithmic prediction and automation aspects that AI brings to SCM processes. From a practical perspective, AI boosts operational efficiency by automating tasks, optimizing routes, and managing inventory, leading to cost savings and faster response times. It enhances supply chain resilience, enabling rapid adaptation to market changes and disruptions. So, it is evident that companies must embrace AI to attain these benefits. Finally, from policy making perspectives, policymakers should encourage AI adoption to enhance supply chain sustainability and compliance with environmental standards, offering incentives for its use in improving resource efficiency and regulatory adherence.

In conclusion, the integration of AI within SCM offers multiple significant of advantages, ranging from enhanced operational efficiencies and cost reductions to higher levels of customer service and improved product quality. The potential of AI for SCM is immense as AI technologies rapidly improve and become more affordable and accessible. AI becomes an integral part of the digitalization journey, enabling companies to transform into digital and data-driven entities.

5.2 RQ2. Challenges associated with the integration and utilization of AI in SCM

AI offers immense benefits to Supply Chain Management (SCM) yet integrating it into daily operations is complex. Numerous challenges accompany the development and deployment of AI in everyday operations. While many of these challenges are technical others refer to various aspects of organizational work. Awareness and preparation for these challenges are crucial for companies aiming to successfully transition into the new digital AI era. The research identified five categories of challenges, which are reviewed in the subsequent paragraphs.

First, from the research it is evident that mostly widely spread and most severe issue is data, specifically its availability and quality. Very often it was a big issue when building SCM AI applications and required lots of effort to overcome.

There are often instances when "gaps in data history" occur, when data formats are inconsistent over time, or data is completely absent. AI models perform best on large-scale data, optimally characterized by the five Vs of big data: Volume, Velocity, Variety, Veracity, and Value. However, it is apparent that not all companies possess data with all such attributes, leading to significant challenges in the deployment of effective AI systems. The competence of AI is closely tied to the

quality of the data on which it is trained, therefore solving the issue with data quality is central to building and using AI applications.

It leads to a clear practical implication for organizations: the need for robust IT infrastructure. Developing IT infrastructures that can efficiently manage, process, and analyse an increasing volume and diversity of data is a central task for companies transitioning from traditional SCM systems to advanced digital frameworks. This requires investing in skilled human capital, IT infrastructure, as well as engaging in strategic partnerships with consultants and IT service providers.

The second category of challenges relates to integration issues and problems with IT infrastructure. When integrating AI in SCM the study reveals multiple issues with IT infrastructure and system integration issues. Examples of such challenges are Legacy Systems Compatibility, Data Siloes, API Limitations, Scalability issues and Re-source Constraints and many other. Integration and infrastructure issues can disrupt AI deployment by causing data access bottlenecks, reducing compatibility, limiting growth, and compromising security and accuracy.

From practical viewpoint it implies that the solutions may include developing robust internal IT infrastructures and implementing scalable cloud solutions, which can significantly improve data handling capabilities. Furthermore, as companies and supply chains dive deeper into the digital world, they must consider equipping themselves with a wider range of critical digital capabilities. Automation, mobile technology, digital collaboration platforms, advanced cybersecurity, user experience design, compliance technologies will increasingly be critical for successful operation in the future business environment.

The third major group of challenges relates to a lack of expertise and skilled talent. The research found a barrier in the form of expertise and talent deficits. Examples include a shortage of skilled AI professionals, gaps in training for current employees, and difficulties in attracting top talent in a competitive market. Such deficits can stall the development, integration, and effective operation of AI systems within SCM. As supply chains become increasingly reliant on complex technologies, there is a growing need for specialized skills such as data science, AI algorithm development, and systems integration.

Pragmatic implication for companies would be a solution with investing in training programs and upskilling to enhance the existing workforce’s capabilities in relevant technologies. Also, making partnerships with academic institutions can help to secure a pipeline of skilled professionals.

The fourth category of challenges concerns change management. Implementing AI within SCM reveals change management challenges. Key obstacles include resistance to change from

employees, lack of alignment between different departments, and the issues of integrating AI with existing business processes.

Solutions can be comprehensive change management strategies that include clear communication of the benefits of AI, involvement of stakeholders in the planning and implementation phases, and continuous training and support for employees. Also, deploying a phased approach to AI adoption with pilot projects and feedback loops can help manage the transition more smoothly. As demonstrated by the COVID-19 pandemic, external environments are vulnerable and lack stability. Accordingly, embracing change management practices becomes crucial. This includes fostering agile culture, open to technological innovations, and being flexible and adaptive to the dynamic demands of modern SCM environments.

Finally, the study revealed that high costs also present significant issues. Research shows the implementation of AI within SCM can be affected by the high costs. These expenses include the procurement of hardware and software, hiring or training staff, and the integration of AI systems with existing IT infrastructures.

Practical advice for firms will be to manage this situation by exploring options of scalable cloud-based AI solutions that minimize the need for upfront hardware investments. Another option would be leveraging open-source AI tools and platforms can also reduce software expenses while still allowing businesses to acquire solutions to fit their needs. As technology progresses, it often becomes more accessible and economically feasible. Therefore, companies are encouraged to track market developments to potentially discover AI solutions at reasonable cost.

Comparing the survey results with prior research, the findings are consistent with those of studies conducted by other researchers. Monika Shrivastav's review, based on both scholarly work and practical scenarios, identifies key obstacles such as disparate data sources, resistance to adopting AI, change management difficulties, and the absence of a robust AI governance framework (Shrivastav, 2021). Clouard identifies four significant challenges in AI adoption: data restrictions, mistrust in technology, technological constraints, and the high costs involved in AI implementation (Clouard, 2022). Hangle et al. highlighted technical limitation in AI adoption emphasizing that despite the generation of large amounts of data, it remains ineffective unless organized (Hangl et al., 2022).

Research findings on the challenges of AI adoption in SCM present significant implications for policymakers. They have many opportunities to mitigate these challenges. For instance, establishing regulations and standards that guide the ethical and effective integration of AI in SCM could provide substantial support. Additionally, to address the shortage of skilled personnel, policymakers

could endorse workforce development initiatives that equip workers for the evolving demands of AI-enhanced supply chains. Furthermore, for companies committed to high environmental standards, policymakers could offer subsidies and tax incentives to support AI adoption, encouraging more sustainable and climate-neutral operations.

In summary, adopting AI in SCM presents numerous challenges. Nevertheless, companies should not be discouraged. On the contrary, they should actively embrace these challenges, channelling the necessary resources and efforts to overcome them. Many organizations that have embarked on the journey of AI integration highlight that, although the process is intense, it is also highly educational and rewarding.

6 Conclusions

The chapter revisits the core findings of the research, summarizing how the results effectively address the research questions. The chapter continues with sharing limitations of the study and suggesting topics for future research on the domain. The chapter concludes with acknowledgements to people who provided considerable contribution to this research work.

6.1 Main findings

The thesis has investigated the application of AI in SCM nowadays and the expectations for the future. Valuable insights have been gathered that will significantly assist future developments in this field.

Artificial Intelligence (AI) is transforming Supply Chain Management (SCM) across several critical dimensions, including resource optimization, operational efficiency, and cost reduction. AI-driven predictive maintenance models enhance resource utilization and prevent costly repairs, thereby saving on expenses. AI applications improve SCM by accelerating operational processes and enhancing accuracy in demand forecasting and inventory management, which is essential in today's volatile market conditions. Furthermore, AI automates routine tasks, freeing human workers for more complex duties, and plays a vital role in integrating emerging technologies like IoT and blockchain into SCM systems. AI's ability to process and analyse vast amounts of data significantly aids in decision-making, especially in complex retail environments where it helps optimize pricing strategies. Additionally, AI increases transparency in supply chain operations, improves product quality, aids in regulatory compliance, and enhances customer experiences. In transportation and logistics, AI enables more efficient, real-time monitoring and routing decisions, reducing energy use, and promoting sustainability, thus supporting businesses in adapting to current challenges like climate change effectively.

However, it is important to acknowledge the challenges that slow down adoption of AI in SCM. The research outlines key challenges and solutions for integrating AI into Supply Chain Management (SCM), focusing on data quality and availability, integration issues, expertise shortages, change management, and high costs. Effective AI deployment is hindered by data issues and integration challenges with existing IT systems, which can be addressed by enhancing IT infrastructures and adopting cloud solutions. The scarcity of skilled AI professionals necessitates investments in training and academic partnerships. Change resistance within organizations requires clear communication strategies and phased AI adoption. Cost concerns can be mitigated by using scalable cloud-based solutions and open-source tools. These measures are essential for fostering agile, resilient SCM practices capable of adapting to dynamic market conditions.

Despite challenges, the future potential of AI in Supply Chain Management (SCM) is immense. The value and benefits of AI are expected to grow significantly with advancements in technology, particularly in fields such as the Internet of Things (IoT), blockchain, robotics, and more. These developments will not only enhance the capabilities of AI but also integrate more deeply and effectively across various SCM processes, driving greater efficiency and innovation.

Companies are encouraged to embark on the journey of AI adoption in Supply Chain Management (SCM), as it will become an indispensable tool in the future. Adopting AI will necessitate a deep and profound transformation of company operations and will require significant effort. However, companies should not feel discouraged; instead, they should be brave and determined to pursue this path to future success. Embracing AI not only prepares businesses for upcoming technological shifts but also positions them competitively in an increasingly digital marketplace.

6.2 Limitations and opportunities for further research

In addition to the limitations mentioned in Section 1.4, an additional constraint should be highlighted. This limitation stems from the methodology adopted. Although multiple case studies are widely regarded as a robust research method, it is crucial to acknowledge that results from a qualitative methodology involving a limited number of companies may not easily generalize to a broader population.

Despite its limitations, the study offers compelling findings, providing clear insights into the application of AI across different processes in SCM. Future research can explore in detail a notable lag in AI adoption among SMEs given the substantial number of such companies in Europe and their significant contribution to the EU economy. Other potential direction for future study can be conducting a benchmark analysis of AI tools, systems, and software available for SCM processes which will be very beneficial. Another interesting topic of research of contingency scenarios where AI and digital systems become unavailable or function with limited capacity. There is an urgent need for training programs that address rapid SCM transformation from AI adoption, which is avenue for another potential research. Other very important topics are security and ethical considerations. Research on security is vital as digital risks increase and the digitalized share of SCM grow. Study from the ethical perspective can include such topics as visibility of ethical trade-offs, understanding the consequences of misconfigurations in AI-driven SCM systems, and ideally designing, and measuring a set of ethical guidelines to ensure responsible AI usage.

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Appendices

Appendix 1. Case study protocol

Source 1. Face-to-face Interviews (via Microsoft Teams)

#	Questions	Research Question #
1	Could you share the size of your company? Would you classify it as small, medium, or large?	
2	What is your role within the company and how it relates with supply chain management?	
3	For how many years has your company been using AI in supply chain management?	
4	Why do you believe the company decided to introduce AI tools? What was the background of this decision?	RQ1
5	What is the value that AI brings supply chain management?	RQ1
6	How would you characterize the extent of AI usage in your supply chain management processes? Would you consider it at a beginner, intermediate, or advanced level? Why do you consider this level?	RQ1
7	Could you elaborate on how the AI capabilities for SCM were developed or acquired by your company?	RQ3
8	What specific AI applications has your company implemented to enhance supply chain management?	RQ2
9	In which areas of supply chain management has your company applied AI?	RQ2
10	What specific AI technologies your company uses, such as machine learning, optimization algorithms, NLP, other?	RQ2
11	What are the benefits your company has experienced from using AI in supply chain management?	RQ1
12	What challenges, if any, has your company faced while integrating or using AI in supply chain management?	RQ3
13	Can you specify which challenges refer to AI implementation phase and what are the operational challenges after AI introduction?	RQ3

14	What are your overall thoughts / summary on the role and impact of AI in supply chain management?	RQ1
16	How do you envision the use of AI in supply chain management in general by the year 2030?	RQ4
16	In 2030 what do you think will be the portion of SCM tasks fully managed by AI?	RQ4
17	What do you think about the risk of AI taking human jobs in SCM?	RQ4
18	Anything you would like to add on the topic that were not discussed?	

Source 2. Interviews on digital media platforms

1. Digital materials: Interviews with SCM professionals from the company on the topic of AI applications in SCM.

Source 3. Internal documents.

1. Digital materials: Internal documents about I projects.

Source 4. Official documents.

1. Company`s Website: information on company`s AI projects in SCM.
2. Website of Companies providers of AI: Information on customer stories on AI projects.
3. News and Press: news about the company and how the company applies AI in SCM.