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The Impact of AI Innovations on Drug Availability and Cost Efficiency in Pharma Supply Chains

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BUSINESS
SCHOOL

Department of Marketing, Strategy and Operations

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Resumo

Esta dissertação investiga o papel da Inteligência Artificial (IA) nas cadeias de abastecimento farmacêuticas (PSCs), com foco nos desafios atuais, níveis de adoção, benefícios percebidos em termos de custos e disponibilidade de medicamentos, bem como nas barreiras à implementação. O estudo foi guiado por quatro perguntas de pesquisa, abordando a extensão da adoção de IA, seu impacto na eficiência de custos e na disponibilidade de medicamentos, além dos riscos e perspetivas futuras.

A pesquisa integrou uma revisão de literatura com um inquérito online aplicado a profissionais da área de cadeias de abastecimento farmacêuticas, obtendo uma amostra de 111 participantes. O inquérito forneceu informações sobre o uso atual da IA, benefícios percebidos da sua implementação e barreiras que continuam a limitar a sua adoção.

Os resultados indicam que a adoção da IA já é significativa, com maior impacto em conformidade regulatória, logística, manufatura e otimização de inventário. Os participantes mostraram grande otimismo quanto à contribuição da IA para melhorar a disponibilidade de medicamentos e a eficiência de custos, além de anteciparem crescimento no futuro. No entanto, também destacaram obstáculos como incerteza sobre retorno do investimento, restrições orçamentárias e desafios regulatórios.

O estudo contribui para a discussão académica ao evidenciar barreiras financeiras e culturais pouco exploradas e ao enfatizar a importância da previsão de procura e o potencial para a sustentabilidade. Para a prática, realça a necessidade de casos de negócio claros, orientação regulatória e melhor comunicação interna para facilitar a adoção da IA.

JEL Classifications: L65 - Industry Studies: Manufacturing (Chemicals • Rubber • Drugs • Biotechnology • Plastics); O33 - Technological Change: Choices and Consequences • Diffusion Processes

Key words: Artificial Intelligence (AI), Pharmaceutical Supply Chains (PSCs), Cost Efficiency, Drug Availability.

Abstract

This thesis investigates the role of Artificial Intelligence (AI) in pharmaceutical supply chains (PSCs), focusing on current challenges PSCs are facing, adoption levels, perceived benefits in regard to costs and drug availability and barriers to implementation. The study was guided by four research questions addressing the extent and areas of current adoption of AI, its impact on cost efficiency of PSCs and on drug availability, as well as risks and future outlook.

Research was done, integrating literature review with an online survey of professionals working in pharmaceutical supply chain roles. The survey provided a sample of 111 participants. It gave insights into how AI is currently used, perceived benefits stemming from implementation, and which are the barriers and risk that continue to limit adoption.

The findings show that AI adoption within PSCs is already widespread, with most common areas affected being regulatory compliance, logistics, manufacturing and inventory optimisation. Respondents expressed great optimism on how AI is improving drug availability and cost efficiency. They also provided an optimistic outlook for the future, however also highlighting barriers such as uncertainty about return on investment, budget concerns and regulatory challenges, all of which need to be addressed if firms are to increase adoption.

The study contributes to academic discussion by highlighting under researched financial and cultural barriers and by emphasising the growing importance of forecasting and potential for sustainability. For practice it highlights need for clear business cases, regulatory guidance and effective communication and education within organisations to enable simpler AI adoption.

JEL Classifications: L65 - Industry Studies: Manufacturing (Chemicals • Rubber • Drugs • Biotechnology • Plastics); O33 - Technological Change: Choices and Consequences • Diffusion Processes

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Glossary:

AI: Artificial Intelligence

PSC: Pharmaceutical Supply Chain

SC: Supply Chain

R&D: Research and Development

GMP: Good Manufacturing Practices

FDA: Food and Drug Administration

WHO: World Health Organisation

EMA: European Medicines Agency

Introduction

The pharmaceutical supply chain and logistics play a crucial role in ensuring that essential medicine reaches patient in the most efficient times and from the company's perspective, in a cost-efficient manner. This industry's supply chain is particularly complex due to the involvement of many stakeholders such as regulatory agencies, suppliers of raw materials, manufacturers, distributors and healthcare providers. In the recent years the industry has faced new challenges such as increasingly varying demand from customers, higher cost of manufacturing and transport of drugs and the decrease of product life cycles to name a few. These changes have been calling for pharmaceutical companies to look for ways to increase the time and cost efficiency of their supply chains (Moosivand et al, 2019). If we put the challenges aside and look at possible solutions, in the last few years Artificial Intelligence (AI) has emerged as a transformative new technology that is slowly being implemented across many industries and it has the potential to tackle the complex challenges which the pharmaceutical supply chain faces and help increase drug availability to patients and reduce costs for the businesses.

Implementation of AI in the pharmaceutical supply chain is gaining potential due to its ability to provide enhanced decision making, predictive analytics and maintenance, real-time forecasting and its ability to automate processes. Supply chain management is one of the functions which have the greatest potential for optimization through AI due to the solutions such as machine learning techniques, predictive maintenance systems and continuous estimation techniques which can help reduce costs, improve demand forecasting, optimize logistics and improve supply chain integration and transparency. However, even with all of the potential benefits which AI-driven solutions can bring, adoption in pharmaceutical supply chain is still in early stages and the potential positive impacts on drug availability and cost efficiency need to be research and investigated in detail (Chui et al, 2018). This paper aims to study the degree to which available AI-driven solution can contribute to the efficiency of the pharma supply chain as well as find and explore the challenges which it might face that can obstruct its widespread implementation.

Background and Context

The pharmaceutical supply chains (PSCs) have historically been highly sensitive to different types of disruptions due to the regulatory hurdles, raw material shortages, transportation delays,

seasonality and sensitive product transport where special conditions are needed such as drugs which require permanent refrigeration (Moller, 2024). One of the recent events which called more attention to the need for a more resilient and efficient pharma supply chain was Covid-19, where lockdowns around the world reduced availability of work force, restricted international trade and travel, caused significant changes in demand, created supply shortages due to closure of sites and created longer transportation and lead times (Vora, 2023). Due to these disruptions in the recent years and the complexity of the supply chain evaluating supply chain risks is becoming a priority in order to achieve maximum efficiency across the entire chain, and this is another area where AI can potentially play a major role. Additionally, the supply chain model of the pharmaceutical industry has not changed much in the last 30 years before the pandemic relying inefficient inventory management systems and manual tracking which has contributed to the traditional challenges such as stock imbalance and wastage (Greenrose, 2023).

The last substantial improvement of the pharmaceutical supply chain (PSC) was the implementation of just-in-time (JIT) inventory management, this strategy helps manufacturers procure raw materials only as they are needed. The rarity of significant improvements and changes to the PSC in the last decades present an opportunity for new technologies such as AI to come to the forefront. AI nowadays offers many potential solutions to the above-mentioned challenges such as helping provide end-to-end visibility throughout the entire supply chain (SC) ecosystem to find potential risk factors (Greenrose, 2023). Generative AI with the ability to search and analyse offers solutions such as negotiation advisory, virtual assistants and automatically generated reports which can help across many functions such as procurement, distribution and manufacturing (Shah et al, 2024). There are some major pharmaceutical companies which have been investing in AI solutions in the past few years such as Sanofi, Novartis and Pfizer however most of it is clinical trials and target identification rather than supply chain and it is still an underutilized and under researched technology in this sector (Pecci, 2023).

Problem statement & Research Gap

Even though in the recent years the adoption of AI in companies and more specifically in supply chain management of firm in different sectors, has increased, the specific impact on the PSC and logistics remains insufficiently studied. Existing studies highlight the potential of AI solutions on different parts of the SC, however there is a lack of a comprehensive study to

understand the real-world impact of AI on drug availability and cost efficiency. Moreover, it is essential to further research the risks and benefits of AI-driven solutions due to the concerns such as AI bias, data privacy and compliance with regulations which can be an obstacle for its adoption.

This study aims to fill the research gap on this topic and provide valuable insights on how AI-driven solutions have the potential to impact the PSC in terms of cost efficiency and availability of essential drugs for end patients. The focus will be on the manufacturing and distribution parts (procurement and distribution of finished products) of the SC, where AI can be used to improve its functions. Through research of existing data such as case studies, industry reports and articles, analysis of data and interviews or potentially a survey with industry experts, this study will provide a comprehensive insight into the potential positive impacts which AI can have on the cost efficiency and drug availability, while taking into consideration and researching the risks and challenges which can oppose its adoption.

Research Objectives & Questions

Objectives

These are the main objectives that this study will be focusing on in order to gain a comprehensive understanding of the topic and answer the research questions:

1. To analyse the potential of AI-driven solutions in addressing supply chain disruptions and drug shortages
2. To evaluate potential cost-efficiency benefits of AI implementation across different stages of the pharmaceutical supply chain
3. To examine risks and challenges connected to the adoption of AI in the pharmaceutical supply chains
4. To gather and analyse first hand data on AI adoption in the pharmaceutical industry
5. To analyse real-world case studies and industry reports on supply chain optimization driven by AI innovations

Research questions

Following are the research questions this study aims to answer through research of primary and secondary data and information to gain a valuable insight into the possibilities of AI in PSC and contribute to this area of research:

RQ1: What cost-saving advantages does AI bring to the pharmaceutical supply chain?
RQ2: How does implementing AI in pharmaceutical supply chains impact drug availability?
RQ3: What are the key risks and challenges of implementing AI in the supply chain of the pharmaceutical industry?
RQ4: How have pharmaceutical companies already successfully implemented AI within their supply chains?

Significance & Justification of the study

This study's significance is shown in its potential to extend the knowledge we have on AI's contribution to supply chain functions in the pharmaceutical industry as well as other sectors and provide valuable insight on how this relatively new and ever evolving technology can contribute to the cost efficiency and drug availability of the complex supply chains of pharmaceutical companies. The study will provide up-to-date information on a technology that is still evolving and is in a major topic in today's business. The knowledge gained from this study will benefit many stakeholders such as the pharmaceutical companies, suppliers, AI technology developers, healthcare providers and policy makers.

From the academic aspect this study will add to the to the growing field of research of AI and its adoption and implementation in different sectors and functions of a business. It will provide new knowledge on the growing topic of supply chain management optimization through AI-driven innovation, providing empirical evidence on its effectiveness in this field. The study will also address the research gaps and serve as the basis for further research in on the potential for AI implementation in the PSCs.

From the industry standpoint this research can have a significant meaning as pharmaceutical companies can use the finding to better understand and eventually implement AI into their supply chains where to benefit from improved cost-efficiency and increase the availability of drugs. The study can benefit stakeholders across the entire supply chain as they can use the knowledge to have a more end-to-end integrated and transparent supply chain. It will help policy makers better understand the topic in order to develop the regulatory framework which will enable a structured and ethical use of AI solutions. It will also provide

information on the barriers and challenges for different industry stakeholders and help them better understand how to tackle them or if the risks are worth the rewards.

As pharmaceuticals are essential to the quality and longevity of the lives of all people, there is a need for optimization of the very supply chains which provide the population with essential drugs. This study will contribute to the research of the potential impact new technologies, such as AI, have on the supply chain of this crucial industry.

This introduction has outlined the potential of Artificial Intelligence's involvement in the improvement of cost-efficiency and drug availability within the supply chain of the pharmaceutical industry. By investigating the background, research gap, objectives, research questions and significance of this study, this section establishes the foundation for further research. The next chapter of the study will provide and detailed and comprehensive research of the already existing literature on the topic of AI adoption and implementation in the pharmaceutical supply chain and provide kay findings, identify research gaps which the study will address and highlight areas which need further investigation.

1 Literature review

Pharmaceutical supply chains (PSCs) have been facing major challenges in the past years due to disruption such the Covid-19 pandemic, changes in regulatory barriers, inefficient inventory management and demand fluctuations on a global scale. However, in those same years a new, trendy technology has emerged as a potential transformative solution, called Artificial Intelligence. This technology has potential of providing a promising solution to key challenge, however it is still in early stages of adoption and needs further research to see its potential to improve cost efficiency and drug availability in PSC. This chapter will focus on the already existing literature connected to AI application in PSC focusing on different areas where optimization is possible and looking at potential risks and challenges (Moller, 2024; Vora, 2023).

This chapter is organized in key areas of research to give a comprehensive view on the topic. First, the structure and dynamics of PSCs are examined, to give and understanding of how supply chains (SC) work in this industry and the differences and specifics compared to traditional SCs of other sectors. Within the first part the study will also take a deep-dive into the industry-specific challenges and inefficiencies which PSCs face, to unveil where AI can come into play for potential improvements. Next, a broader look of AI's role in supply chain management, providing a foundation of where it is already used across different industries and how it is connected to the challenges of the pharmaceutical industry. In the third part, the research delves into AI's implementation specifically in the pharmaceutical industry, where it is used and where it has potential to be adopted in connection to the challenges identified in the first part. The study then moves into explaining the financial implication of AI's adoption in PSC, to understand potential cost-efficiency benefits and possibilities for lowering financial risks and expenses. In the final part, this chapter assesses potential risks and challenges connected to the adoption of AI which include regulatory and ethical risks as well as technical barriers (Moosivand et al, 2019; Chui et al, 2018; Pecci, 2023).

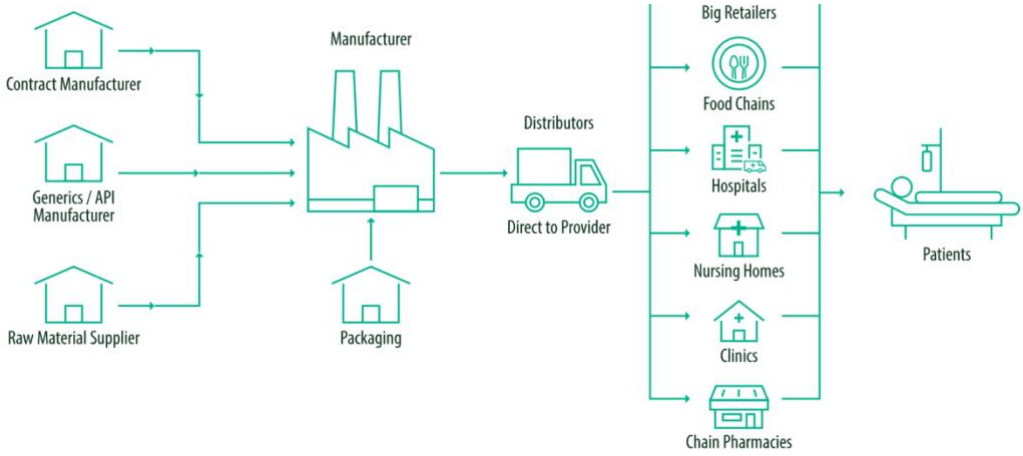
1.1 Pharmaceutical Supply Chain: Overview and Challenges

1.1.1 Overview and Industry-specific Characteristics

A broader explanation of a Supply Chain (SC) is an interconnected and complex system which take raw materials and transform them into finished product, then delivered to the customers. There are several stakeholders which make up the traditional supply chain, first are producer

of raw materials then vendors buy and sell these materials to manufacturers who take the raw materials and transform them into finished products, the next part are logistics providers who transport the goods around the globe to the retailers who sell to the end consumer, or the goods are transported directly to the end consumer. Supply chain managers are another part of the SC, and they are there to ensure the whole process runs smoothly and without interruption (Mentzer et al, 2001).

Figure 1.1: Pharmaceutical Supply Chain layout. (Source: Infosys,2020)



Although the Pharmaceutical Supply Chain (PSC) is similar to the traditional one it does have some industry-specific characteristics. Normally, the PSC is divided into manufacturing and distribution phases, to put simply. There are some differences between Generic and Brand drug supply chains, where brand drug manufacturers source raw materials from producers and then usually produce the drugs in self-owned manufacturing plants, rarely through third-party manufacturers. While for Generic drugs it is not unusual to be produced by a third-party manufacturer and then shipped to the self-owned manufacturing plant of a generic pharma company to be processed further and moved to packaging (Infosys, 2020).

The manufacturing process of pharmaceuticals follow strict guidelines ensuring safety, quality and efficacy. The World Health Organisation (WHO) created a guide called Good Manufacturing Practice (GMP) where the main focus is mitigating risks connected to mix-ups and cross-contamination (Vaittinen, 2016). Following manufacturing is packaging, which is divided into primary and secondary packaging which ensures drug integrity, prevents contamination and satisfies regulations such as the EU's Falsified Medicines Directive (FMD) which prevents falsified medicines entering the market, by mandating serialisation and tamper-proofing (Smith et al, 2015). Finally, the drugs are distributed to providers which then either sell or provide drugs patients. In the distribution phase also, the pharma industry has many

specific characteristics, such as regulatory guidelines for example in the EU, Good Distribution Practice (GDP), the need for permanent refrigeration for many medicines, need-based distribution where quantities being transported can vary and also seasonality which impacts the need of certain drugs (Moller, 2024). Reviewing all that it is obvious that the SC of pharma companies is specific and complex, but what are some of the main challenges that PSCs are facing?

1.1.2 Challenges of Pharmaceutical Supply Chains

One of the critical parts in logistics and supply chain management is demand forecasting and inventory management. Even though the PSC is a complex system which make the execution of the forecasting processes tougher, the goal of forecasting is the same as with any other business and that is to gain a reasonably accurate estimate of future demand for a product. It uses historical data and current state of environment from the different perspectives such as political, social, economic etc. One of the main challenges of this study is the accuracy of forecasting and with that also management of inventory levels (Merkuryeva et al, 2019). This presents such a significant challenge in the pharma industry due to unpredictable market conditions, seasonality of demand and patent expirations or approvals. The consequences of inaccurate forecasting of overestimating demand can cause excess inventory and wastage especially with drugs that have shorter shelf life. When demand is underestimated the risks can be stockout or delays which can be life threatening in this industry (Moosivand et al, 2017). Demand data is required for both push and pull types of a supply chain which even further emphasizes its importance. The answer to why this became such a big challenge in this sector is due to pharmaceutical industry being one of the strongest R&D industries and historically paying most of its attention to R&D and much less to the development and optimization of its supply chain. However, with expiration of patents which led to a significant increase of generic drug companies who focus on being efficient in its supply chain, the entire industry had to turn its attention to the challenges of future demand forecasting and inventory management (Merkuryeva et al, 2019).

The next problem which PSC's face is the high costs of distribution due to mostly temperature sensitive pharmaceutical products. These types of products need to be maintained under a certain temperature for the entire duration of their journey from when they begin the journey to the final destination. These products need to be shipped, handled and stored at different temperatures which need to stay consistent most of the times under ambient

temperature and even below freezing, this is called the Cold Chain. The biggest concerns are transportation and storage where temperature maintenance is needed both on the ground and in the air (Yoon, 2014). High costs come when drugs which need to travel by cold chain, are exposed to temperatures that are outside of the prescribed range of clinical protocol and package insert, which is called temperature excursion. Temperature excursion spoils these pharmaceuticals causing high costs for pharmaceutical companies. More specifically, the pharmaceutical industry loses roughly $35 billion annually due to temperature excursion making distribution one of the most important challenges in this industry (Myles & Church, 2021). In 2015 a survey of supply chain experts by the Pharmaceutical & Medical Packaging News found that 31% of drugs shipped had to be refrigerated, 17% were frozen and 32% should not be allowed to freeze and 51% were shipped at ambient, which puts in perspective the significance of temperature-controlled distribution and the challenges that come with it (Sykes, 2018).

In addition to the above-mentioned challenges, the PSC faces significant and constantly changing obstacles related to compliance with regulations and quality assurance. There are many regulations which are also constantly changing which makes it complex and difficult to follow. In manufacturing, the Food and Drug Administration (FDA) in the US has its Current Good Manufacturing Practice (CGMP) regulation which controls the manufacturing, processing and packaging of drugs and makes sure it is safe for use (FDA, 2025). In the EU the main regulation for manufacturing is the EU Commission's own Good Manufacturing Practices (GMP) which have 2 directives, one applying to product for human use and the other for veterinary products (Vaittinen, 2016). The reason for compliance with regulations being such a big issue for pharma companies is that if the regulations are not followed for any reason, it can lead to quality problem, waste and in extreme cases even death of patients. If we look from a business perspective not complying with regulation can lead to substantial fines, for example the FDA fined Ranbaxy Laboratories, $500 million dollar and banned them from exporting drugs to the US, after finding out their facilities did not meet the CGMP standards in 2013 (Joseph, 2020). Distribution in PSC is also regulated, the World Health Organisation (WHO) has its Good Storage and Distribution Practices for Medical Products, which sets the guidelines for maintaining of safety and quality of pharmaceutical products in the process of storage and distribution (WHO, 2019). Same as for manufacturing the EU has its own regulation for distribution of pharmaceutical product, called Good Distribution Practices (GDP) which in this case applies only for human use and ensure safety and quality of the

products (EMA, 2025). Since this is quite a complex topic it represents a substantial challenge which needs to be addressed by the pharmaceutical companies in the future.

The final challenge this study will focus on is the issue of ensuring sustainability and ethical sourcing in the PSC. One of the main challenges of sustainability is of course, the environmental impact of PSC's. Emissions represent a major role and are relevant to this study because more than 70% of all emission that are produced by this industry come from their supply chain. Another important part is the waste as pharma companies produce 300 million tons of plastic waste annually (Heim et al, 2023). The second part of this challenge is ensuring an ethical supply chain. The lack of an ethical supply chain not only harms the reputation of the company but also hurts the safety of patients around the world. One reason for this challenge is the lack of transparency, traceability and accountability across the entire supply chain. With complex supply chain and lack of transparency companies cannot know if their raw materials are sources sustainably and if labour practices are ethical and humane at every stage of the supply chain process (Bengtsson, 2023).

1.2 Current implementation of Artificial Intelligence in supply chain

In this subchapter of the literature review the research focuses on where Artificial Intelligence (AI) is currently being implemented in supply chain activities regardless of the industry and the benefits it has on the impacted functions. This broader research will help understand use cases from other industries which can then also be applied to the Pharmaceutical Supply Chain (PSC). Additionally, this part will be connected to the challenges mention in the previous subchapter for a clearer overview of how it can apply to the pharmaceutical industry (Moller, 2024; Vora, 2023).

1.2.1 Examples of current use of Artificial Intelligence in supply chain

Dash et al, state that AI is define as the ability of a computer to independently solve problems that they have not been explicitly programmed to address. In the recent years AI's benefits connected to optimization of supply chain management have been a hot topic in business. Through research we found many potential benefits such as improved demand forecasting which can lead to more efficient inventory management and reduced stockout or even waste, AI's ability to enable real-time visibility and transparency across the entire supply chain which helps with communication and disruption responses and research has shown AI could even

improve decision-making with its ability to analyse data which can improve the overall performance of the supply chain and business. The AI technologies behind these benefits are machine learning algorithms, robotistic process automation (RPA), natural language processing (NLP) and others (Shahid et al, 2024).

Even though it is still a relatively new technology this part focuses on the real-life examples where AI solutions have been used to improve supply chains. The first example connects to the first challenge that PSC's face which was mentioned in the previous subchapter, demand forecasting accuracy. Businesses are already using AI tools which process, automatically analyse and predict data, then providing a precise and reliable forecast of demand. The benefits for the firm are reduced costs related to different functions, from distribution to manufacturing, due to optimization of their ordering and purchasing. Additionally, it finds patterns and trends which helps with better strategy and time efficiency. Both benefits are connected to drug availability and cost-efficiency if we connect it to the pharma industry (Dash et al, 2019). For example, in the United Kingdom, the National Grid which is the largest distribution network of electricity uses the product "Deep Mind" developed by Google which helps to reliably predict supply and demand fluctuations and changes and even considers weather-related inputs such as wind speed and atmospheric pressure (Singh & Sharma, 2022). Another example is a company called Otto, which is a German online retailer that began using a deep learning algorithm which was primarily developed for use in connection to particle physics, it analysed billions of data records and 200 variables including weather reports, transactions and the search queries on Otto's website. The AI program was able to predict the demand for the next 30 days with 90% accuracy, greatly improving the firms order and purchasing strategy and optimize inventory management (Schaefer, 2019).

Another major challenge identified was the high cost of inefficient distribution due to the sensitivity of the product in the pharma industry, there are examples where AI has been used to improve distribution that could be related to this issue. One part of the distribution issue is storing of the products in transition an example where AI is used to improve warehouse efficiency is Suning, a Chinese retailer, which used 200 AI-powered robots in a 100-square meter warehouse to load close to 10,000 moveable shelves. The reason was for people to not chase the shelves but wait for the robot to come to them with the shelves. Their findings were that the use of these robot can reduce labour by 50 to 70 percent. And the picking efficiency of goods can be improved by more than 300% percent compared to manual picking with accuracy of almost a 100% (Zhang, 2019). The other part of distribution is transportation of the products and the outdoor environment is a more complex and requirement are more strict when it comes

to application of AI. One of the more well-known examples is the delivery company UPS partnering with drone firm Zipline to use unmanned and AI powered drones to deliver emergency medical products such as blood in Africa (Dash et al, 2019). Another example which is better connected to complex pharma cold chain delivery is the example of Chinese firm Shunfeng which developed unmanned aerial vehicles (UAV) for large logistics, which have a range between 500 and 2000 km, load of 300 to 2000 kg and a cruising speed of 200-300 km/h, which supplements its regional logistics. The final example connected to distribution is the so-called "Vision van" from German car maker Mercedez Benz which is an all-electric car which must drones attached to it used to deliver goods. The use of AI in the vehicle would be shown in its ability to cross-reference the delivery location of each product within the van and find the fastest route to the destination/s, this would happen immediately after receiving the goods and the van would set off on its route. The two self-piloted drones would be used to deliver smaller parcels while the car itself keeps driving to deliver other goods. This last example would greatly improve the efficiency of logistics, however for now it is only a concept vehicle (Zhang, 2019). These AI applications not only contribute to the distribution challenge but also to the sustainability issue with lower emissions and waster by raising the efficiency of logistics.

Artificial Intelligence has potential and is also already being used to improve regulatory compliance. There are different tools in use, one of them being Natural Language Processing (NLP), which was mentioned in the beginning of this subchapter. It can analyse and interpret vast amount of text data which includes regulatory submissions, it can extract key information and automatically generate summaries which can help employees understand essential information quickly and efficiently (Boopathi & Raja, 2024). This technology is already being implemented in the oil and gas industries where AI systems gather data on emission levels of the offshore drilling operations and then NLP processes this data and the regulatory data to create structured reports to meet regulatory standards. These systems can create real-time reports and immediately alert if the levels of emission don't comply with the regulatory standards (Ajegbile et al, 2024). Besides NLP there are also other AI systems which can improve regulatory compliance such as Automated Document Management (ADM) which is a tool that helps to prepare and also submit regulatory documents which improves time efficiency and reduce errors which consequentially minimize the potential for non-compliance and accelerate regulatory approval processes which highly relates to the pharmaceutical industry. Machine Learning (ML) is another AI tool for regulatory compliance, and it uses algorithms that allow computers to learn from data and make decisions and predictions while not having

to be programmed for each task they do (Boopathi & Raja, 2024). One example of a complete solution connected to regulatory compliance is JPMorgan Chase's COiN (Contract Intelligence) platform which leverages AI to analyse legal document and create reports of the key information making it easier to comply with legal requirements of contract and regulations (Batte & Walugembe, 2024).

Sustainability was already mentioned when researching AI application in the distribution part of SC, however it is an important challenge of PSC's that has its own examples connected to the implementation of AI. Two major US companies use AI technologies to reduce their emissions and carbon footprint, first is General Electric, they use a digital twin technology to optimize production processes while predicting and reducing their energy consumption in all facilities. The other example is UPS who use a system called ORION which helps with finding the best delivery routes through advanced AI algorithms and that enables the company to enjoy higher delivery efficiency due to reduced travel distances as well as idle time and also reducing fuel consumption and carbon emissions, bringing sustainability to their logistics (Rokibul et al, 2024). Another issue connected to sustainability is ethical sourcing of raw materials and ethical labour practices. OpenSC is a digital platform company which its Automated Claim Verification (ACV) system that leverages data science and machine learning to analyse digital information like live video monitoring, satellite images and worker biometric data in order to verify of low-carbon and ethical production in the supply chain as well as monitoring safe, ethical and humane labour practices, ensuring slaver-free supply chains (Stuit et al, 2022). Unilever is another company which leverages AI and machine learning benefits to improve the sustainability of its global supply chain. They use the technology to follow the agricultural practices and deforestation that may affect its raw materials, one example in this case is palm oil. With the use of satellite imagery to see patterns of deforestation, Unilever can make better more informed decision about their sourcing which helps with improving resource efficiency and ensures ethical sourcing (Deshmukh et al, 2024). In this subchapter the study touched on many examples of AI's implementation in numerous industries and connecting these examples to the PSC challenges and cost-efficiency and drug availability factors. Next, is the research on the current use of AI in the pharma sector and potential uses in the PSC.

1.3 Use of Artificial Intelligence in the Pharmaceutical Industry and future potential in the supply chain

In this subchapter of the literature review this study dives into the examples of current AI applications in the pharmaceutical industry. This will include other functions not only the supply chain to understand in what stage of adoption of AI this industry currently stands. Then the research will also focus on future potential for implementation of AI in connection to the main challenges identified in the first part of the literature review (Pecci, 2023).

1.3.1 Current use of AI in the pharmaceutical supply chain

Since Artificial Intelligence (AI) tools have been such a hot topic in the recent years it is expected that there are many pharmaceutical companies which are already using the technology in different sections of their operations. One of the most know cases is the US multinational pharma corporation, Pfizer, which is one of the largest pharmaceutical companies today, one of their adoptions of AI was a partnership with Concreto HealthAI in 2019 to advance their work in precision Oncology, using real-world data in connection with AI to identify new, more precise treatments and speed up the time of their development (Patil et al, 2022). The most famous example connected to Pfizer's use of AI was their partnership with IBM Watson Health in order to use IBM Watsons machine learning (ML) and natural language processing (NLP) capabilities in drug discovery where they benefit from a more efficient selection process of patients for clinical trials as well as more efficient identification of new drug targets. Another example of a famous pharma company using IBM Watson is Novartis, the major Swiss pharma corporation uses the technology provided by IBM to target breast cancer drugs. The strength of Watson for drug discovery is that it is a cloud-based platform which hold millions of Medline abstract, over a million of medical journal article and information on four million patents which is far more information that any human researcher can go through (Tung, 2018). Janssen, the pharmaceutical division of the international conglomerate Johnson & Johnson, is another firm which has a strong history of using AI in its operations, for example the company partnered up with Komodo Health, a platform which uses AI algorithms in combination with stores of claims codes as well as other patient data to match patients to clinical trials which makes the trials more statistically reliable. They also signed a deal in 2020, with Tempus which is a company that uses predictive algorithms to find bio markers focusing on oncology (Savage, 2021). Another example of Janssen is their 2019 partnership with a French AI startup to develop a drug design system. This AI system enables the identification of molecules that the desired

criteria based on its capacity to explore chemical space, which is the space that cover all possible molecules and chemical compounds, with high efficiency and speed (Patil et al, 2022). The aforementioned Novartis had another well-known multilayer partnership in 2019 to develop an AI innovation lab that serves the purpose of leveraging AI and data to improve and accelerate drug discovery and reduce costs (Vermeer & Thomas, 2020).

These examples have mostly been in drug discovery and connecting firms to patients, however there are examples of the use of AI in PSC's. Once again Pfizer is the example with their use of AI in the manufacturing stages of the COVID vaccine. To optimize its process of manufacturing and other supply chain processes they used AI algorithms to predict possible disruption, improve the time efficiency of gaining raw materials and increase the volume of production without lowering the quality (Saini et al, 2025). Merck is another global pharmaceutical company from the US which uses AI technologies in the supply chain processes. One example is their use of AI to create simulations of various scenarios and model complex production processes to find potentials for process optimization such as batch sizes, reduce cycle times, reorganize production layouts to minimize waste, downtime and disruption. They also use it for monitoring equipment condition with which they can predict failures and optimize maintenance schedules in manufacturing (Hemamalini et al, 2024). Roche, another Swiss pharmaceutical giant, developed and AI-based machine learning (ML) system with has the ability to monitor and analyse real-time data with it receives from sensors which are installed around the entirety of its warehouses, from that the ML system can help with waste reduction, improvement of efficiency and optimize inventory management (Guo, 2023).

1.3.2 Potential future use of AI in Pharmaceutica Supply Chains

The study now delves into the research of potential future uses of AI technologies in PSC's, more specifically connecting them to the challenges identified in the first part of the literature review. The first opportunities explored are connected to the pharmaceutical cold chain logistics, which represent an important challenge due to the temperature sensitivity of many drugs and the difficulties that come with its transportation and warehousing. AI can be used to solve a major issue which is that in cold chain logistics the products go through many different links where data and information is not integrated, with an integrated tracking system which can track the product in real-time ensuring the quality and efficiency of their distribution. The AI tool processes data and information at every stage of cold chain distribution and tracks the product (Goshwam et al, 2024).

Another solution to the transportation challenge are autonomous vehicles (AV) which use AI for analysing data and information which they convert into decision making for path planning and navigating traffic congestions. Examples of this are the fully automated and electric truck named Otto which was developed in 2016 and Volvos, Vera truck which are delivery trucks made to deliver heavy goods and services in the most cost and time efficient ways, minimizing accidents by using intelligent cameras and other sensors to operate, detect and position more smartly. This would optimize the supply chain in term of costs and time and would also tackle another challenge which is sustainability by providing a cleaner and safer alternative to regular delivery trucks (Bathla et al, 2022). Monitoring of warehouses using machine learning (ML) is already being used by Roche as mentioned before and could be used even more efficiently in the future with the use of AI powered robotics such as autonomous mobile equipment, mobile rack and robotic arms transport and lays system which would greater precision and efficiency inside the warehouses by making it more autonomous and less labour-intensive saving time and money (Ramamoorthy, 2024).

As explained before firms in other industries are already using artificial intelligence for improving regulatory compliance with Natural Language Processing (NLP) models, which could also be adapted to the pharma industry. These types of systems could go through regulatory data and contracts such as the above-mentioned EU's Good Manufacturing Practices (GMP) and FDA's CGMP as well as other regional and local regulations to create summaries for humans responsible for compliance. They could monitor any real-time changes and avoid big fines and other cost related to compliance failures (Boopathi & Raja, 2024).

As explained when looking at other industries, many companies are already using AI for demand forecasting even some pharma companies. AI-driven technologies such as ML and neural networks help firms to analyse extensive datasets, find trends and make accurate predictions. These technologies can help predict demand using factors such as purchase history data and seasonality which is very important in pharma, ensuring optimized raw material orders, inventory placement across its supply chain and delivery plans. One example of this is SAS Forecasting which is a ML tool the analyses macro and micro-economic variables to help companies align production schedules with demand and avoid disruptions from unpredictable events. this ensures and efficient supply chain which minimized times, costs and waste. Another example is Google Cloud AI which uses neural networks to provide extremely accurate forecasts of demand. This program can process massive sets of data in real time making it a great tool for complex and global supply chains such as the pharmaceutical (Nweje & Taiwo, 2025).

Last topic to be discussed as a potential future of AI use in pharma industry is the highly popular Generative AI (GenAI) which has the potential to be used to enable faster production cycles making supply chains more agile and adaptive to disruption and change. It also has connections to regulatory compliance by generating reports containing statistical analysis plans, tables, listings and figures, GenAI can also predict Health Authority Queris (HAQ), formulate the responses and providing help with submission strategies for responses (Shah et al, 2024). All of the above mentioned current and potential uses of AI are in one way or another connected to drug availability and cost efficiency of the pharmaceutical supply chains. The challenges identified in the study are being addressed by AI in some firms and there are many more potential applications. In the following subchapter the research dives into the financial implication of AI in the PSC's.

1.4 Financial Implication of Artificial Intelligence in Supply Chain

Throughout the literature review the study explored many current and potential options for AI's implementation within the supply chain (SC), specifically in the pharmaceutical supply chain (PSC), there was also mention of how these technologies can affect the cost efficiency of PSCs. The subchapter looks a bit further into the financial implications, the implementation of AI technologies can have if adopted (Chui et al, 2018; Shah, 2024).

One of the main challenges that was addressed was the logistics connected to cold chain and there were many researched solutions which would improve drug availability but also cost efficiency. Through benefits achieved with AI solutions such as optimized delivery routing that reduce fuels consumption, improved delivery times, pharma companies could significantly reduce their costs. A study shows that companies could reduce their fuel cost by 15 percent when using AI technologies. Autonomous vehicles and the previously mentioned Mercedes trucks with drones, can reduce cost by reducing the number of drivers as well as being even more time efficient by delivering multiple packages at once, using the drones. Looking at another challenge identified earlier in the study, forecasting demand and inventory management can also be financially impacted by AI. A study looking at many use cases from different sectors found that using high quality real-time data in combination with AI to predict demand on specifically regional scale as well as health trends, has the potential to decrease waste and spoilage of drugs in the pharma industry and help keep inventory levels at the most efficient point, therefore improving sales by 5% to even 10 % due to the improvement in margins stemming from the solution. These number may seem like big saving but wastage due

to inefficiencies of demand forecasting as well as health trends disruption cause a serious problem for the pharma industry and AI could be one of the solutions (Chui et al, 2018).

The problem with ethical sourcing within the larger sustainability problem, can be improved through AI powered Augmented sourcing. This technology can help find ethical supplier with high labours standards, it can help prepare documents such as purchase orders, invoices and contracts, it also has the power to analyse market conditions, pricing information and even information about the suppliers to improve decision making. Additionally, the technology can be used as a negotiation aid by analysing data from past negotiations and outcomes finding important patterns. All of these solutions can lead to reductions of procurement management cost of up to 5-10 percent, a study by McKinsey shows. The last cost efficiency from using AI technologies, this research investigates, is through improved regulatory compliance. As companies need to follow strict regulations and good manufacturing practices (GMP), AI can come in as important tool to find deviations from regulations, follow latest updates and trend in the regulatory changes, find causes for discrepancies and ultimately provide possible solutions and corrective actions. The technology generates important document and simultaneously check for regulatory compliance. This can lead to significant improvements in efficiencies, the aforementioned McKinsey study found that this can potentially increase the productivity of pharma companies by 35 precent in regard to the regulations connected to the PSC's and other. These efficiency increases lead to faster times leading to a substantial reduce in cost. The effectiveness of the investigation can also be improved by between 30 and 40 percent which can lead to massive monetary saving if it can lead to avoiding fines which can be substantial when connected to non-compliance with regulations (Shah, 2024). While currently existing literature is optimistic about the current use and potential for AI to bring cost efficiencies, there is a lack of realized evidence of cost savings, highlighting the gap between theoretical potential and what is demonstrated in practice. Exploring this is also one of the main goals of this study's research and focus in the empirical study chapter.

1.5 Risks and Challenges Connected to adoption of AI in Pharma Supply Chains

Throughout this chapter, there has been a lot of mention of possibilities and opportunities for AI's use in PSC, however this type of technology also brings its risk and challenges. In this subchapter the study goes into some of the potential risks pharma companies could face if

adopting AI into their supply chain (SC) (Vellanki, 2024; Schmidt et al, 2020; Ismael 2024; Nozari et al, 2022).

One of the industry specific challenges for PSC is the constant changing and evolving regulations such as the GxP standards. GxP mean Good Practice and are guideline for safety, consistency and efficiency in the pharmaceutical industry and life sciences. The X in GxP refers to Manufacturing, Laboratory, Clinical and Distribution. For this study the two important ones are Good Distribution Practices (GDP) and Good Manufacturing Practices (GMP). Implementation of AI solutions into PSC can cause unforeseen risks that could lead to non-compliance with the aforementioned standard if it is not correctly implanted. These regulations are also complex, rigorous and constantly changing which can be a challenge for the implementation of AI. To combat these challenges pharma companies must document everything and collect, maintain and keep data about everything, and this data must comply with ALCOA standards, which are the standards for data integrity in the pharma sector. If data is kept according to standards there are even AI solutions which can potentially help with regulatory compliance of other AI solutions in the supply chain (Vellanki, 2024).

Another potential risk that companies might face when implementing AI solution in their supply chains is cybersecurity. When using big data and AI to create a smart and efficient supply chain, there is a need for connections between different devices as well as different functions of the supply chain, to ensure real-time collaboration between the different steps in the SC. This, however, increases the risks level of potential attacks, with many devices and machines connected in a bigger network, a vulnerability in device or machine can open the entire network to the risk of a cyber-attack. Pharma companies which work with sensitive machines, materials and information need to be adaptable and have systems in place to anticipate and find machine-level and even organization-level vulnerabilities and protect them from potential attacks (Nozari et al, 2022).

One common challenge when talking about AI implementation is the concern with privacy, trust and transparency which are crucial for the adoption of AI solutions in any industry, especially in the pharma industry and its SC. Trust can be undermined due to the lack of understanding of how AI works by the stakeholders, not knowing how AI systems come to conclusions can make organizations hesitant to implement AI and rely on it for important task such as demand forecasting, drug distribution and even regulatory compliance. This however is changing due to the popularity of AI technologies, them becoming almost ubiquitous in people's lives, everybody is getting educated on the topic and the understanding of the systems will improve in the future. Transparency of AI models is closely connected to trust because it

is essential for understanding how AI works and arrives at conclusion, however it is still a challenge to achieve suitable transparency without compromising the performance of these AI models. And the main concern if connected to the pharma sector is the privacy concerns. Due to AI models having access and the processing of massive amount of sensitive and also confidential data such as business information, patient information and drug research information. There need to be robust privacy-preserving systems in place in order to prevent any data leaks and breaches and these systems are also required by regulatory organizations (Schmidt et al, 2020).

The final challenge with AI's implementation, is the organizational readiness, which can play a pivotal role in successful implementation of AI in SC's and is connected to some other challenges mentioned above. Companies need to have an updated technological infrastructure which include, high-speed internet, very strong cybersecurity measures and advanced computing capabilities. The workforce also needs to be highly skilled for proficient work with AI, which can require education and upskilling of existing employees or recruiting new talent. If these measures are not followed, significant barriers can emerge for AI adoption and the process of adoption can be hindered causing the supply chain to be less efficient and even less resilient. It is key for companies to look and address these challenges with a holistic approach in order to successfully implement AI and reap the potential benefits (Ismael, 2024).

To conclude, the literature review explored key challenges in the pharmaceutical supply chain and potential way to address them with AI solutions. The study looked at how AI technologies can improve drug availability, as well as exploring its financial implications on the PSC's. While there are many benefits which AI can bring to the pharma industry and its supply chains there are still many questions on how it can tackle the challenges with its adoption and implementation. Further research is needed to fully understand how AI is impacting and how it can impact the pharma supply chains in the future. Building on the findings form literature review, the next chapter will outline the research methodology which will be used to gather, analyse and evaluate primary data to find out more on how AI can impact drug availability and cost efficiency in the pharmaceutical supply chains (Vellanki, 2024; Schmidt et al, 2020; Ismael 2024; Nozari et al, 2022).

2 Empirical Study

2.1 Methodology

The purpose of this chapter is to better understand which research approach was used in the study to find the effects of AI innovations on drug availability and cost efficiency in the pharmaceutical supply chains (PSCs). Due to the complexity of the topic and the relatively new technologies examined in the study, the approach used was a quantitative with a structured online survey as the main method for data collection. This chapter dives deeper in the research design which includes the specifics of the data collection methods, selection criteria, which methods were used for data analysis as well as ethical considerations. Combining the analysis of secondary data such as industry reports, scientific articles and case studies as well as the collection of primary data which was done through the survey ensured a comprehensive research and results.

2.1.1 Research design

The secondary data was conducted through reviewing many industries report, academic research such as case studies, researching regulatory documents and scientific articles to get the foundational understanding of the current landscape of AI in the PSCs and even a broader look at how AI is impacting supply chain management. This data complements the knowledge gained from primary data collection by providing context, highlighting trends as well as revealing gaps in the existing research on the topic.

Primary data was collected using a structured online survey. Interviews were considered, however, it was decided to conduct the survey as the main source for primary data because it gathered insights across a larger sample than the interviews would have. Due to the target audience being quite a niche but also still a diverse group of professionals in PSCs and related fields, gathering data from more participants with a survey ensured that measurable insights were achieved and gave a better understanding on how AI is impacting drug availability and cost efficiency. It also enables both descriptive analysis of the results as well as comparative analysis.

2.1.2 Data collection method

Primary data was collected using a self-administered online survey created in Google Forms. The survey included mostly closed-ended questions but also some open-ended questions based on the literature and goals of the thesis. The closed-ended questions used Likert scales, multiple-choice and ranking formats which helped gather quantifiable data. Open-ended questions additionally provided the respondents the opportunity to share other examples, opinions and insights using their own words.

The survey link was distributed via LinkedIn groups for pharmaceutical and supply chain professionals, direct messaging on LinkedIn, email outreach to pharmaceutical companies and professional networks through personal connections. The use of LinkedIn ensured that a larger number of professionals was reached and also ensured that it was targeted to the right audience. Gathering responses through professional and personal connections also ensured getting the correct targeted responses. The survey was open for 8 weeks and then the data was downloaded and analysed.

2.1.3 Target Population and Sample

The target population were professionals working in or closely connected to the pharmaceutical supply chain (PSC). These were:

- Supply chain managers
- Logistics and distribution specialists
- Regulatory compliance experts
- IT and Data management professionals
- Procurement and sourcing specialists
- Other professionals connected to PSC

The survey managed to gather a total of 111 valid responses. This number is considered sufficient and robust given the niche nature if the target audience. The different roles and experience levels of respondents ensured a diverse perspective within PSCs. It was found to be sufficient for descriptive and comparative statistics, drawing sufficient insight and identifying patterns and drawing meaningful conclusions.

2.1.4 Survey Structure

The survey was structured into 4 sections:

1. Demographic questions: role, years of experience, size of organization and region of operations)
2. Perception of AI in supply chains: Liker-scale questions measuring perception related to costs efficiency and drug availability.
3. Challenges and risks: questions addressing the risks and challenges to AI adoption
4. Current and potential applications: multiple-choice and open-ended questions exploring where AI has already been implemented and where they see potential in the future.

2.1.5 Data analysis

Data analysis was mostly conducted in Excel and was additionally supplemented with statistical tools where required. The following analysis was conducted:

- Descriptive statistics: frequencies and percentages were used to summarize questions related to demographics and multi-selected questions.
- Likert-scale analysis: frequency distributions, measures of central tendency (to explain agreement levels), measures of dispersion to summarise variability and also Top-2 Box analysis in order to point out the consensus.
- Cross tabulations: comparing perceptions across different demographic groups.
- Visualisations were also conducted in order to better show the result of the analysis, and they include: bar charts, stacked Likert Plots and summary graphs of means and standard deviations.

This approach allowed the gathering of important insights and overall patterns.

2.1.6 Ethical considerations

Participation in the survey was completely voluntary. The introduction of the survey explained the purpose of the study, the anonymity of responses and their right to withdraw. Every respondent was provided with a consent statement in the beginning of the questionnaire which they had to accept in order to continue. No personally identifiable data was collected ensuring anonymity to reduce bias. It was also explained to the participants that data was stored securely and was used solely for academic research purposes according to ISCTE and SEB LU ethical guidelines.

2.2 Results and findings

In this chapter the findings extracted from the survey are presented on the impact of AI on pharmaceutical supply chains (PSC). It is divided into three sections. First section presents the demographic profile of the respondents in order to give context on the characteristics of the whole sample. The second section presents the survey results in relation to the study's research questions and objectives, which include adoption level of AI in PSCs, where it is used and perceived benefits. Lastly, the third sections observe obstacles or risks to implementation and outlook for the future potential of AI. The results are presented with both descriptive statistics as well as visualisation. This will ensure we have a clear and precise interpretation of the findings.

2.2.1 Demographics

From the survey, a total of 111 valid responses were collected. The sample includes professionals with diverse levels of experience, a range of different roles and different company sizes to ensure a comprehensive view of the impact that AI has on the industry.

Figure 2.1: Respondents by professional role (n and %)

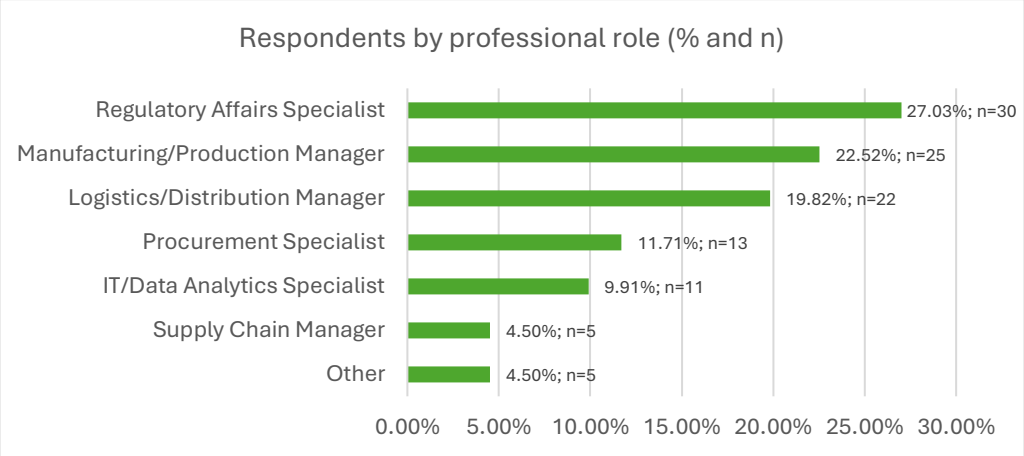


Figure 2.1 summarises the professional roles of all the 111 survey respondents. As the graph shows, there are three major groups that stand out, the largest is Regulatory Affairs Specialist (n = 30; 27,0%), followed by Manufacturing/Production Manager (n = 25; 22,5%) and Logistics/Distribution Manager (n = 22; 19,82%). In the middle there are two roles, Procurement Specialist (n = 13; 11,7%) and IT/Data Analytics Specialist (n = 11; 9,9%). And there is also Supply Chain Manager on the lower side with 4,5% and 5 respondents. There is also a small number of other additional roles such as cyber security, scientist and finance, which

together represent another 4,5%. As mentioned in the beginning, it is quite a niche target group but also with quite diverse roles. The diversity of roles gathered by the survey which span regulatory, logistics, manufacturing and more, suggest that this sample provides a broad range of perspectives which are relevant to AI implementation in the PSCs.

Table 2.1: Respondents by Years of Experience (n and %)

Years of Experience	n	%
Less than 2 years	7	6,31%
2–5 years	53	47,75%
6–10 years	26	23,42%
11–20 years	12	10,81%
More than 20 years	13	11,71%
Total	111	100%

The survey also explores the distribution of respondents based on their professional experience in the pharmaceutical industry. Table 2.1 shows that the largest share of respondents (47,75%) have 2 - 5 years of experience. 23,42% of respondents reported having 6 - 10 years of experience. Two smaller but still notable groups with 11 - 20 years and more than 20 years of experience, represent 10,81% and 11,71% respectively, giving the perspective of more senior level professionals. Finally, the smallest proportion represented by 6,31% of respondents are those with less than 2 years of professional experience. While the answers are slightly skewed towards professionals with 2 - 5 years of experience, other groups are also strongly represented giving a balanced view of perspectives on AI in PSCs across all experience levels.

Figure 2.2: Distribution of respondents by Company Size (n and %)

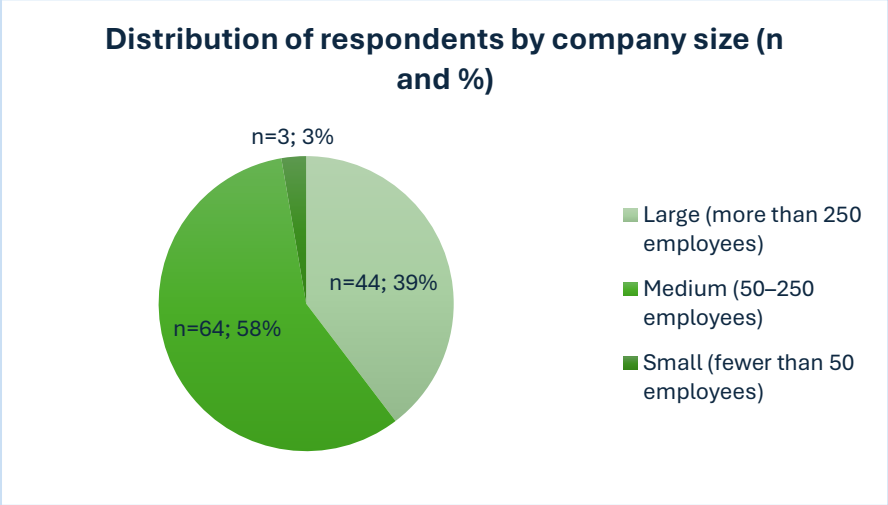


Figure 2.2 represents the distribution of respondents by company size. The distribution was quite heavy on the medium and larger companies, with only 3% of respondents reported working for small companies with less than 50 employees. The largest share of respondents at 58% work for medium companies with 50 - 250 employees and large companies with over 250 employees accounted for 39% of the sample. This suggest that the insights gathered by the survey mainly reflect perspectives from medium to large companies, which reflect that companies of these sizes dominate pharmaceutical supply chains due to their stronger resource and reach.

Table 2.2: Respondent companies' primary regions (n and %)

Regions:	Number of respondents	% of all respondents
Europe	40	36,0%
Asia	37	33,3%
North America	36	32,4%
South America	33	29,7%
Africa	23	20,7%
Australia / Oceania	8	7,2%

The final demographic observes the main regions respondents' companies operate in. As shown in Table 2.2 the respondents' companies are represented in multiple regions, more

specifically, the main three regions are Europe (36,0%), Asia (33,3%) and North America (32,4%). South America (29,7%) and Africa (20,7) represented a smaller but still significant portion of respondents. Australia/Oceania at 7,2% is the least represented region. Percentages do not add up to a 100% because the respondents were able to choose multiple regions as their primary markets. Although the results are weighted a bit towards Europe, Asia and North America the sample is geographically diverse, suggesting global supply chains and numerous regulatory environments.

2.2.2 Current challenges in Pharma Supply Chains

Participants were asked to identify the main challenges that are currently affecting PSCs. The percentages in Table 2.3 do not sum up to 100% but rather show the portion of respondents who chose each of the challenges, since participant were able to select more than one challenge.

Table 2.3: Main challenges in pharmaceutical supply chains identified by participants (n and %)

Challenges of Pharmaceutical Supply Chains	n	% of Respondents
Regulatory compliance	73	65,8%
Cold chain logistics and temperature control	59	53,2%
High cost of distribution	57	51,4%
Demand forecasting accuracy	54	48,6%
Ethical sourcing and sustainability	33	29,7%
Inventory and stock management	32	28,8%
Others	3	2,7%

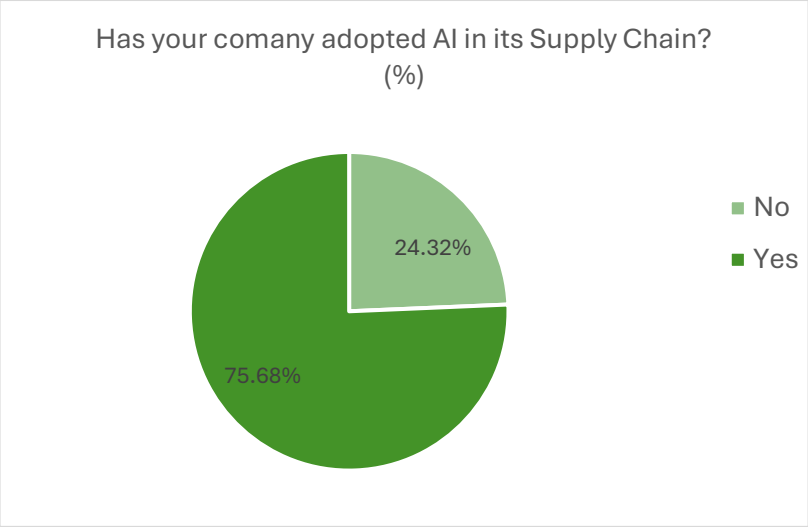
Table 2.3 clearly presents that the main challenges perceived by respondents are Regulatory compliance (66%), Cold chain logistics (53%) and High costs of distribution (51%), all of which were highlighted by more than half of the respondents. Following closely as a major challenge is also Demand forecasting as cited by 49% respondents. Ethical sourcing and sustainability (30%) and Inventory and stock management (29%) were highlighter less frequently, however, still represent a significant proportion of the sample. A small number of respondents (3%) also noted other challenges such as quality concerns which are not very significant.

Overall, the results suggest PSCs are facing a combination of logistical complexities, cost challenges as well as regulatory pressures, alongside challenges connected to inventory management and emerging concerns such as sustainability.

2.2.3 Current Adoption of AI in Pharmaceutical Supply Chains

Firstly, respondents were asked whether their firms currently employ AI within their supply chain operations. As shown on Figure 2.3, 84 (76%) participants reported AI technologies currently being used in their organisations, while 27 (24%) state that their organisations do not use AI currently. Additionally cross-tabulation by organisation size indicated that AI has higher adoption rate among medium-sized firms (86%) compared to the large firms (63%).

Figure 2.3: Current Adoption of AI in Pharmaceutical Supply Chains (%)



Additionally, respondents who reported not using AI (n=27) were then asked about their future plans for adoption. Table 2.4 indicates that a substantial majority of the sample (63%) were "not sure" whether their firms would adopt AI in the future. 22% of them reported there are no plans for adoption in the next two years, while the other 15% stated that there is plans to implement AI in their SCs.

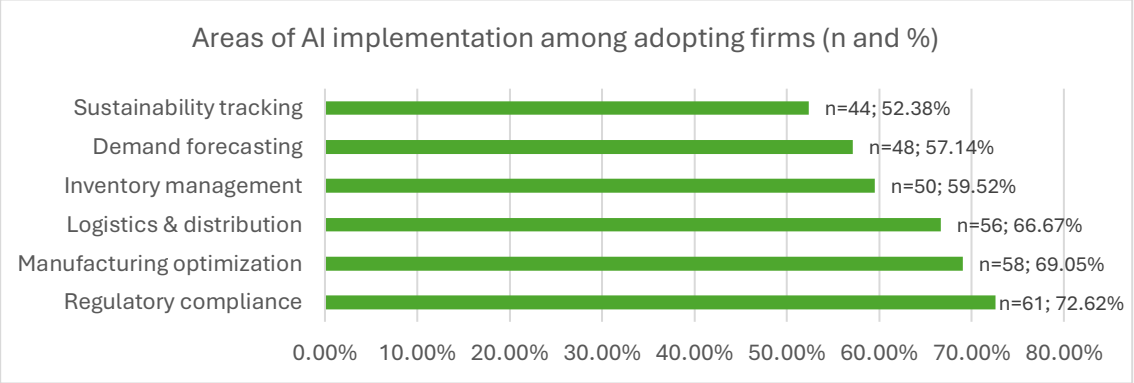
Table 2.4: Future AI adoption intentions among non-adopting organisations

Are there plans for implementation of AI in the next 2 year?	% of respondents	Number of respondents
Not sure	62,96%	17
No	22,22%	6
Yes	14,81%	4
Grand Total	100,00%	27

This data suggests that while there is still quite a substantial percentage of firms which have yet to adopt AI, that a small proportion are outright resistant to adoption, the majority are either planning or undecided which indicates a level of uncertainty but also interest in the potential use the technology.

On the other hand, participants who indicated AI adoption (n=84), were asked to highlight specific areas in SCs where it was implemented. These results are shown in Figure 2.4. Three major areas where AI is used, all of them indicated by more than two thirds of the respondents are Regulatory compliance (73%), Manufacturing optimization (69%) and Logistics & Distribution (67%). Slightly less prominent were Inventory management and Demand Forecasting reported by 60% and 57% of the sample, respectively. The least reported was Sustainability tracking however still highlighted by a significant proportion of respondents (52%). Respondents were also asked which areas they believe were already positively impacted by AI and the results gave the same order of answers as the Figure 2.4 shows, for the areas of implementation, suggesting these areas were impacted positively (See Appendix B).

Figure 2.4: Areas of AI implementation within Supply Chain among adopting firms (n and %)



Altogether, the findings show that AI adoption is already very prominent in PSCs as three-quarters of respondents' organisations reporting implementation. Within these adopting organisations AI is most frequently used in Regulatory compliance, Manufacturing and Logistics, while non-adopters are undecided rather than resistant when it comes to future use.

In addition to SC applications, all participants (n=111) were asked if their organisations used AI outside of SC areas. A majority of the respondents (74,8%, n=83) reported the use of AI also outside of SCs. Respondents were asked to identify where AI is used outside of SCs with an open-ended question, of which the answers were categorized in the categories seen in Table 2.5. Also highlighted in Table 2.5, are the most frequently cited areas where AI is used

outside SCs with IT & cybersecurity (34,9%) and various customer-facing (27,7%) applications. Other significant mentions were R&D and clinical trials (14,5%) and also General office productivity (18,1%). A smaller number of respondents reported legal, and finance also used AI for their operation.

Table 2.5: Areas outside of Supply Chain where companies apply AI, categorized (n and %)

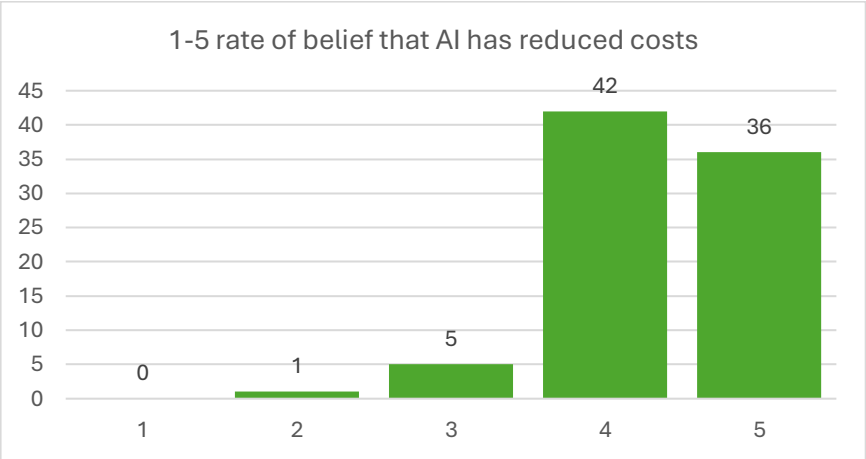
Category	n	%
IT & Cybersecurity	29	34,94%
Customer-facing (Sales, Marketing, Service)	23	27,71%
General Office / Productivity and Other	15	18,07%
R&D & Clinical Trials	12	14,46%
Legal & Finance	4	4,82%
Grand total	**83**	**100,00%**

It is also worth pointing out that 85,2% of those who reported not using AI outside of SCs also reported that they do not use it within their SCs, suggesting that while many use AI broadly, most of those who do not use it in SCs do not use it at all.

2.2.4 Perception on AI's impact on Cost Efficiency

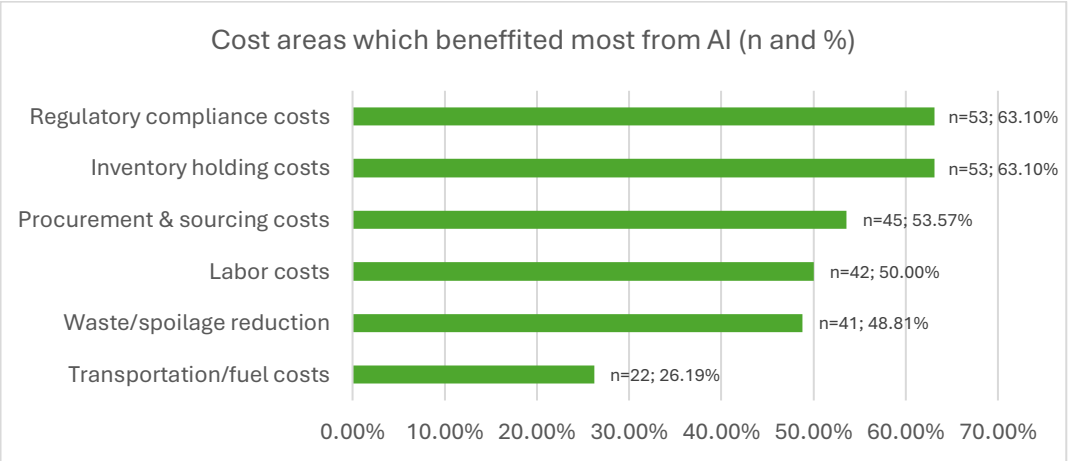
To study the role of AI in cost efficiency of PSCs, participants who reported AI adoption (n=84) were presented with three questions: first a Likert scale question about rating 1 to 5 how much they believe AI has reduced costs, second, they were asked to select up to three cost-related areas benefiting most from AI and lastly to estimate the percentage of cost reductions due to the adoption of AI.

Figure 2.5: Rating from 1 to 5 how much respondents believe AI has reduced operational costs in Supply Chains (n)



In the first question for this part of the survey participants were asked to indicate the level of agreement that AI has contributed to a reduction of operational costs within PSCs. As illustrated in Figure 2.5 the responses were extremely positive. A combined 92,9% picked the two highest answers, 4 and 5 indicating strong belief that AI has indeed reduced costs. Out of all respondents 6% remained neutral and other negligible 1%, disagreed slightly. The mean rating was 4,35 with a standard deviation (SD) of 0,65 reflecting a strong level of consensus AI's contribution to cost reduction.

Figure 2.6: Cost-related areas which benefitted most from AI adoption(n and %)



When asked to indicate up to three cost related areas which benefited most from AI respondents most frequently cited Regulatory compliance costs and Inventory holding costs both being picked by 63,1% of all respondents (n=84). Thos were followed by Procurement,

sourcing (53,57%) and labour costs (50%) as well as Waste/spoilage reduction which were also identified very frequently. Transportation/fuel costs (26,2%) however were picked less frequently as shown on Figure 2.6. Cross-tabulation by years of experience revealed some variations, indicating that less experienced professionals (5 years or less) perceive labour and compliance costs as the most commonly benefiting from AI, while highly experienced respondents (over 20 years) more frequently selected procurement and sourcing costs.

Table 2.6: Estimated cost reductions due to adoption of AI (n and %)

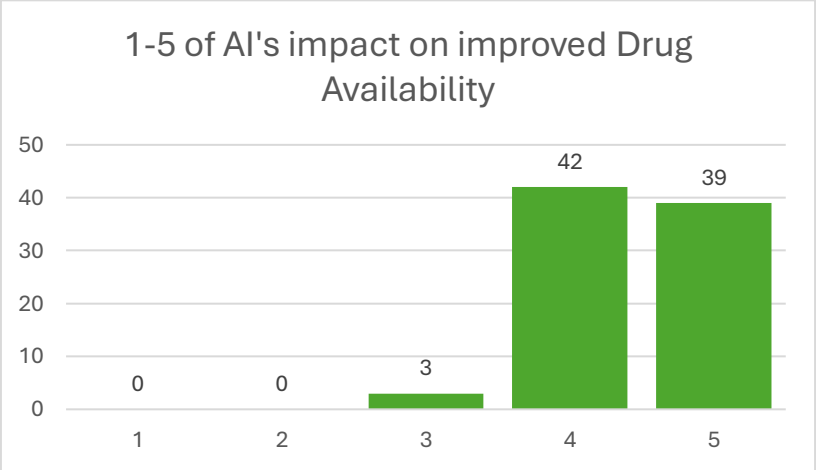
Estimated reduction	n	% of respondents
Less than 5%	1	1,19%
5–10%	24	28,57%
11–20%	26	30,95%
21–30%	9	10,71%
More than 30%	23	27,38%
Unknown	1	1,19%
Grand total	**84**	**100,00%**

As final part of cost efficiency section, participants were asked to estimate cost reduction achieved through AI implementation. As presented in Table 2.6 the most frequently selected range was between 11-20% (31%), closely followed by ranges between 5-10% (28,6%) and over 30% reductions (27,4). An additional 10,7% of respondents indicated reductions between 21 and 30%. A negligible 1,2% each, reported less than 5% reductions or unknown. While the majority (almost 60%) indicated reductions of 5-20%, a significant proportion also experience over 30%, which highlights consistency of reductions while also indicating the potential scale of savings from AI implementation. Comparing answers by years of experience, a clear pattern emerged. Participants which have more than 10 years of professional experience tended to report higher cost reduction with almost all reporting reductions higher than 20%. Less experienced individuals most frequently reported slightly more modest numbers which indicates that senior professionals, who generally have more overview of the organisation and its cost structure, perceived benefits from AI stronger than less experienced individuals.
Overall, the results show that respondents perceive AI technologies to have a significant effect on cost efficiency, reporting savings in multiple areas of PSCs, frequently.

2.2.5 Perception on AI's impact on Drug Availability

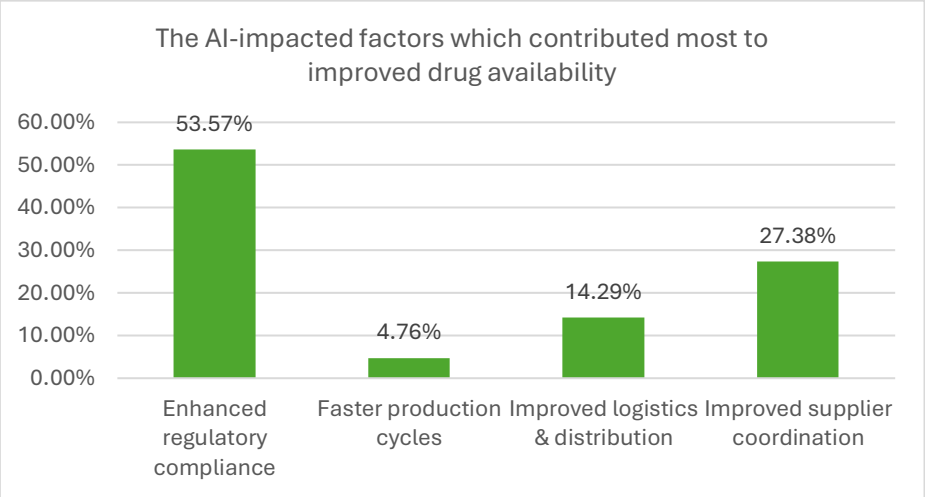
Similarly to the previous subchapter, participants (n=84) were asked three questions related to AI's impact on drug availability: first a Likert scale question rating 1 to 5 how much they believe AI has improved drug availability, second, they were asked to select what they perceive the main contributing factor to improved availability from AI and lastly to estimate the percentage decrease in stockouts since AI adoption. Figure 2.7 shows a similar picture to cost efficiency, indicating a positive perception with 96,4 selecting 4 or 5, which translates that they agree or strongly agree that AI implementation has improved drug availability in SCs. Only 3,6% remained neutral and no respondents disagreeing. The mean score was 4,43 (SD = 0,57) suggesting participants believe AI has a strong positive impact on drug availability.

Figure 2.7: Rating 1 to 5 how much respondents believe AI improved Drug Availability (n)



To get a deeper insight, participants were asked to identify one main AI-impacted factor which contributed to improved drug availability. Figure 2.8 illustrates that more than half (53,6%) of the respondents identified AI driven enhanced regulatory compliance as the main driver for improved drug availability. Over a quarter of respondents (27,4%) highlighted improved supplier coordination, followed by improved logistics & distribution with a lower but still significant share of 14,3%. A much less significant proportion of 4,8% pointed out faster production cycles. Cross-tabulation by years of experience again show a pattern, this time suggesting that senior staff identified improvements to regulatory compliance as the main factor, while the less experienced professionals were more inclined to identify logistics and supplier coordination more frequently.

Figure 2.8: Which factor impacted by AI contributed most to improved Drug Availability (%)



Respondents were also asked to estimate the % of stockout decrease caused by positive impact of AI implementation in PSCs. Two most frequently selected ranges were 5-10% and more than 30% both estimated by 20 (23,8%) participants, closely followed (22,6%) by estimates in range of 11-20%. A significant proportion also chose 21-30% and a much lower portion of the sample reported less than 5% in decreased stockouts. Similarly to cost efficiency, the majority (over 55%) estimated moderate decreases in stockout, however these results are slightly more weighted toward significant benefits (over 20%).

Table 2.7: Estimated percentage of stockout reduction (n and %)

Estimated decrease in stockouts	n	% of respondents
Less than 5%	7	8,33%
5-10%	20	23,81%
11-20%	19	22,62%
21-30%	15	17,86%
More than 30%	20	23,81%
Unknown	3	3,57%
Grand total	84	100,00%

Once again comparing answers by years of experience, showed a consistent pattern, which was almost identical to the one related to cost efficiency. Again, individuals with more than 10 years of professional experience indicated higher benefits from AI implementation choosing

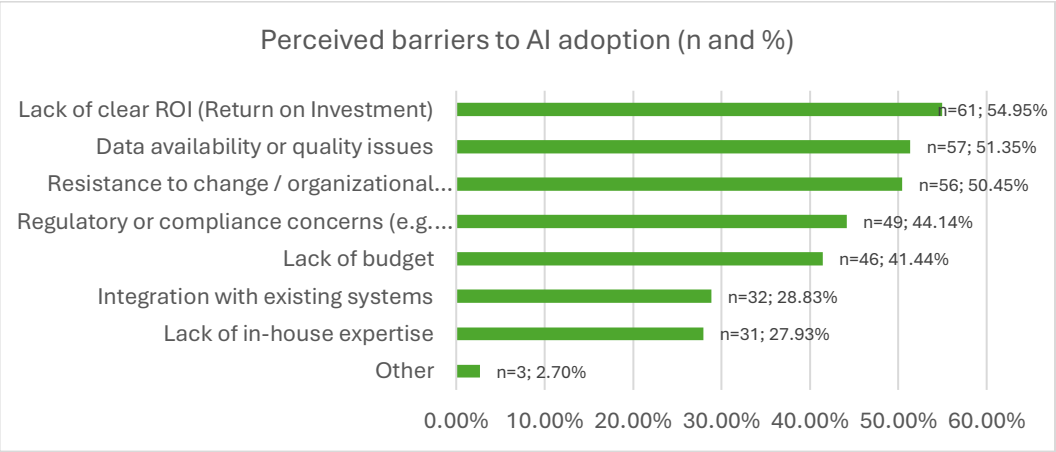
only reductions in stockout higher than 20%. Similarly, less experienced portion of the sample reported slightly more modest estimates.

To sum it all up, the results confirm that AI is perceived as a highly beneficial technology also when it comes to drug availability. Primary drivers as indicated by respondents are improved regulatory compliance and supplier coordination, leading also to moderate to significant reductions in stockouts.

2.2.6 Barriers to AI Implementation and Future Outlook

To research what the potential risks and barriers are to AI adoption in PSCs, all participants (n=111) were asked to identify up to 3 which they felt were most prominent. Figure 2.9 illustrates that the three most frequently indicated risks or barriers are the lack of clear ROI, data availability and quality concerns and resistance to change, all picked by over half of the sample. The other two significant barriers were regulatory compliance (44,1%) and lack of budget (41,4%). Integration with existing systems and lack of expertise were much less frequently pointed out but still represented over a quarter of the respondents each. When comparing the answers by size of the firms, respondents from larger firms (over 250 employees) more often identified data quality and availability as well as resistance to change as the main issues, while respondents from smaller firms (up to 250 employees) the lack of budget and clear ROI as the most pressing challenges to AI adoption.

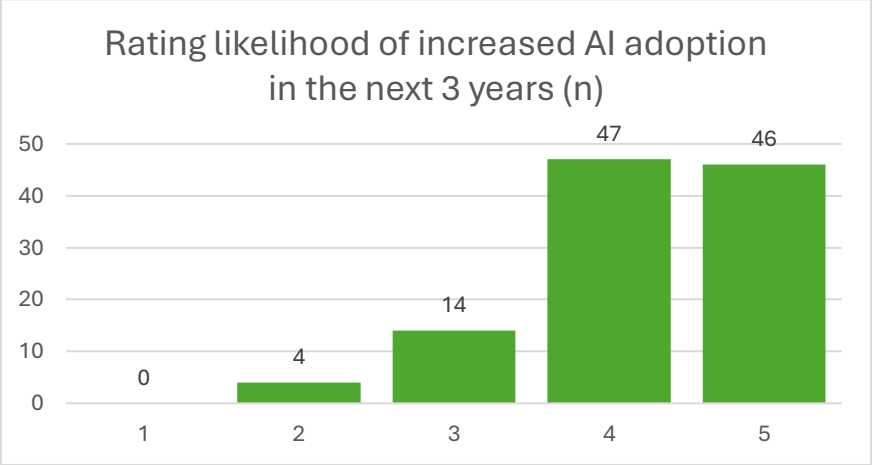
Figure 2.9: Main barriers for AI adoption (n and %)



Looking ahead, participants (n=111) were asked to identify what is the single area withing PSCs which has the greatest potential to benefit from AI. Regulatory compliance (26,1%) and

Sustainability tracking & ethical sourcing (25,2%) were identified most frequently by the respondents suggesting a shift toward sustainable practices also with AI and a further focus on the ever-changing landscape of regulations. Demand forecasting, logistics and the optimization of manufacturing also represented a significant proportion of responses (see Appendix C).

Figure 2.10: Likelihood of increasing AI adoption in the next 3 years (n)



As the final question, the participants rated how likely their companies are to increase the adoption of AI in the upcoming 3 years. The respondents expressed a very positive future outlook for AI adoption, as 83,8% responded as likely (rating 4) or very likely (rating 5) to increase implementation. The mean rating was 4,22 with a standard deviation of 0,8 suggesting a strong level of consensus about the future adoption of AI. An interesting finding was that 78,6% of those who were neutral (rating 3) and a 100% of those who reported the increase as unlikely, were respondents from firms which do not have current adoption of AI in PSCs. While some indicated adoption as likely, the majority (55,6%) remained neutral or responded with "unlikely" (rating 2), indicating that firms which do not currently implement AI show more uncertainty also when it comes to future outlook. Overall, while the future outlook is identified by respondents as positive, they did point out some important risks and barriers which need to be take into consideration for the future.

2.2.7 Summary of results

To summarize, the survey results and findings show that pharmaceutical supply chains are facing persistent challenges such as high costs, regulatory compliance and changes in demand. As reported by a substantial majority of respondents AI adoption is already common in PSC,

with areas most frequently highlighted as logistics, manufacturing and regulatory compliance. Overall, professionals in PSCs and their firms generally have a positive view when it comes to AI's contribution to cost efficiency and drug availability, with a large proportion of the sample reporting substantial cost and stockout reductions. At the same time however, a few important adoption barriers and risks were identified such as lack of clear ROI and data quality issues. Overall, these results both highlight strong perceived benefits and also challenges and constraint that could hinder AI's wider adoption for the future, setting up an intriguing discussion for the next chapter.

3 Discussion

3.1 Introduction to Discussion

In this chapter the study discusses the findings of the survey, interpreting them and tying them to related research questions as well as existing literature explored in literature review. The previous chapter focused on presenting the results in a descriptive manner with minimal interpretation, while the Discussion chapter is meant to prevent a deeper analysis of what the result mean and their implications. It aims to assess if the primary gathered data confirm, extend or challenge existing research and highlight what it reveals in terms of current and future use of AI in PSCs.

The chapter is organised into specific parts, firstly examining the current challenges in PSCs and examining how perception of survey respondents is connected to the literature. Next, the chapter examines the level of adoption and specific areas, interpreting survey results in comparison to the literature. Cost efficiency and drug availability will be two important areas of interpretation and comparisons, followed by the analysis of barriers and risks which may hinder adoption in the future. Finally, it will reflect on the knowledge gathered about the future outlook and tying it all together with theoretical and practical implications, limitations to the study and finishing with recommendations for further research.

3.2 Current challenges in Pharmaceutical Supply Chains

The finding from the survey highlight that the most pressing challenges currently faced by PSCs are regulatory compliance, cold chain logistics and high distribution cost, each identified by over half of the participants. Demand forecasting was also identified as a major issue, while sustainability and inventory management were considered less pressing but still relevant with a significant share of respondents indicating them.

Comparing to current literature, these results are consistent in aligning with the literature, where the heavily regulated PSCs have consistently been emphasized and the issues with compliance pointed out (FDA, 2025; EMA, 2025; WHO, 2019). Highlighter by more than half of respondents, distribution costs, have been a challenge consistently identified in earlier literature findings which suggest PSCs have high overhands compared to other industries due to their exposure to strict handling requirement and fragmented distribution networks (Myles & Chruch, 2021). One major cause of high distribution costs identified by previous research is

Cold chain logistics, which is also a major challenge identified by the survey, is has especially been prominent as temperature-sensitive biological drugs and vaccines become increasingly important. This also implicates that cold chain and costs are connected challenges (Yoon, 2014; Myles & Chruch, 2021; Sykes, 2018).

The growing importance of accurate demand forecasting has been an important topic in pharma recently and the survey reinforces this discussion. While generally less visible compared to regulatory and logistics issues, there are several studies form literature which suggests poor demand forecasting can directly contribute to drug shortages and SC inefficiencies. Moreover, literature also suggest inventory management and demand forecasting are connected making it an even more pressing challenge (Merkuryeva et al., 2019; Moosivand et al., 2017). The fact that almost half of the survey participants identify demand forecasting as a major challenge, implies that it is becoming an increasingly recognised challenges in the industry.

An interesting observation is that sustainability and ethical sourcing were indicted less frequently in the survey, while much of the recent literature has put emphasis on the environmental impact of PSCs, especially when it comes to ethical sourcing of raw materials, waste and emissions produced (Heim et al., 2023; Bengtsson, 2023). One possible explanation is that when it comes to the pharma industry regulatory pressures and immediate operational challenges take precedence over longer-term sustainability goals. This does not necessarily suggest that sustainability is not important, but rather that it comes with more urgent challenges which need to be addressed by management teams for the firms smooth running. Respondents may face short-term risk more often which could introduce some bias with identifying them more often than some longer-term risks.

Overall, the survey finding align closely with existing literature when it comes to challenges faced by PSC, however they also implicate a shift in emphasis towards demand forecasting as a growing issue and sustainability as a long-term one. For managers, these findings would suggest that AI applied to improve compliance and distribution will bring higher return in the short term than sustainability programs. While traditional concerns such as regulations and cold chain logistics (and high costs connected to it) remain dominant both in literature and practice, new identified emerging priorities reflect the ever-evolving complexity of PSCs and the risk that come with it.

3.3 AI Adoption in Pharmaceutical Supply Chains

The survey results showed that AI is already widely adopted in PSC. A clear majority of respondents (75,7%) reported that their firms currently use AI in many areas, mostly in demand logistics optimisation, inventory management, demand forecasting and regulatory compliance. These answers are only partly consistent with commonly identified use cases from the literature (Saini et al, 2025; Hemamalini et al, 2024; Guo, 2023).

This notably high ratio of adoption is an interesting topic given that much of the existing research has described the pharmaceutical industry as slower to digitalise and adopt new technologies compared to industries such as retail and automotive (Schmidt et al, 2020; Vellanki, 2024). The survey findings are reflecting the most recent data which may agree with literature, which suggests that since the COVID-19 pandemic pharmaceutical companies are accelerating their investments in digital technologies to strengthen the resilience of their supply chains (Vora, 2023). Additionally, the increasing availability of industry-specific AI solutions such as IBM Watson Health, Microsoft Solutions and others (Tung, 2018; Vermeer & Thomas, 2020), have lowered the barriers for adoption which were more emphasized in the literature (Joseph, 2020; Moosivand et al., 2017, Merkuryeva et al., 20219).

The survey results also found that adoption patterns were not uniform across all companies. Cross-tabulation illustrated that medium sized firms reported highest adoption level (86%) compared to large companies (63%). This finding suggest that size and structure of firms can influence adoption. These results contradict the resource-based theory which suggests firms with greater resources tend to better absorb risks. The reason behind the results may be that medium firms may be more agile, resource-conscious, while large organisation can be slowed by legacy systems, bureaucracy or even public perceptions.

Finally, the survey also highlighted that AI implementation is not limited only to supply chains as many of respondents reported IT, customer services and R&D as major areas where AI is also being used. This also aligns with reviewed literature which reports that AI has been used in many firms for clinical trials, drug discovery and accelerating the development of new drugs (Patil et al, 2022; Tung, 2018; Savage, 2021; Vermeer & Thomas, 2020). An important observation was that 85% of those who reported no AI adoption within SCs, also reported no adoption outside, suggesting that AI adoption is rarely confined to individual function but rather adopted throughout the enterprise or not at all.

Taken together, these findings imply that pharmaceutical companies are adopting AI more rapidly than previous literature would suggest. Emerging challenges such as regulatory caution

and the need for more resilient SCs are pushing the industry to adapt and increase their digital transformation investments which would support results showing the wider and rapid adoption of new technologies such as AI. The findings of this subchapter directly connect to RQ4, answering that, yes, AI is used in PSCs and providing examples of current areas of AI implementation.

3.4 AI and Cost Efficiency in Pharmaceutical Supply Chains

Primary data findings suggest that professionals in PSCCs perceive AI as having a substantial positive impact on cost efficiency, most commonly in areas such as regulatory, inventory management, distribution and procurement. Estimated cost savings were generally moderate to high suggesting AI has a major impact on cost reductions. Respondents which have more experience in the industry also tended to report higher cost savings, which suggest that those more familiar with supply chain operations may recognize the financial benefits of AI more highly.

Comparing to literature, these findings align with Merkuryeva et al. (2019), who emphasized that better inventory management and forecasting are key to avoid costly over or under stocking. Additionally, Chui et al. (2018), demonstrated that firms using AI for improved forecasting could improve margins by 5-10% by reducing spoilage and optimizing inventory levels. Chui et al., (2018) also pointed out that optimized logistics could reduce fuel cost by up to 15%. Academic literature also highlighted AI-driven compliance tools and improve productivity in various parts of the regulatory process by up to 35% which in turn reduces labour costs, inefficiencies and the risk of fines which can be up in millions in the pharma industry (Shah, 2024). A study by McKinsey also showed that AI powered augmented sourcing and negotiation assisting, can reduce procurement cost by up to 15% (Shah, 2024). All of these align with survey findings which suggest substantial cost reductions and provide answers to RQ1 as examples for cost advantages which AI brings to PSCs.

As reported in the previous subchapter, survey results suggest broader adoption of AI in PSCs, than literature, which is why there is also fewer tangible data on cost reductions related to the pharma industry's AI adoption. Literature also shows some examples outside of the pharma industry where AI has reduced costs in SCs that could be applied in pharma or even already are as the survey is the most current data available, for example a Chinese retailer, Suning which used Ai powered robots to optimize its warehousing and inventory reducing labour costs by up to 70% (Zhang, 2019). This would align with survey results as half of

respondents identified reduced labour costs as a major factor impacted by AI. As demand forecasting is a major challenge, companies such as the UK's National grid and German, Otto are using Google's product Deep mind and deep learning algorithms to predict demand fluctuations, analyse weather reports, transaction and other data to predict demand up to 90% accurately (Singh & Sharma, 2022; Schaefer, 2019). These examples also connect with primary data as demand forecasting is a major challenge and is also already supported by AI, which could also explain the optimistic estimates of cost reductions in PSCs.

Take together, both literature and empirical evidence from this research, point to AI as an emerging enabler of cost efficiency and productivity in PSCs. While the literature maybe points to more moderate benefits and shows less real-world evidence of cost savings, the optimistic estimation by the survey respondents suggests a fast-changing environment where new technologies are already showing cost benefits. The particularly positive perception from highly experienced professionals highlights the growing recognition of AI as a major driver for ongoing financial benefits in the pharma sector.

3.5 AI and Drug Availability in Pharmaceutical Supply Chains

Ensuring drug availability is a central objective of all PSCs, because failure in supply chain management can cause direct harm to patients and healthcare systems. Literature describes PSCs as highly interdependent networks with multiple tier suppliers, strict regulations and long lead times, which amplifies the aforementioned challenges on drug availability (Moosivand et al., 2019).

When it comes to drug availability the survey results suggest an even more positive perception when it comes to AI's influence of improving drug availability compared to cost efficiency. The mean rating of 4,43 with standard deviation of 0,57 emphasize this agreeance further. Respondents expressed that enhanced regulatory compliance, followed by improved supplier coordination and logistics are the main drivers of improved drug availability through AI. When asked to estimate reductions in stockout due to AI adoption, respondents were very optimistic, again showing that more experienced professionals estimate higher benefits from AI.

A recurring theme in the literature is demand forecasting which is the most direct connection to reducing overstocking and stockouts. Literature suggests that modern AI or machine learning forecasting system have been reported to improve forecasting accuracy in other industries while yet to show tangible results in the pharmaceutical industry (Nweje &

Taiwo, 2025). While survey results on adoption show the use of demand forecasting, it is not mentioned as the main driver currently improving drug availability. This would even further implicate demand forecasting as newer challenge being addressed.

As reported by Saini et al, (2025) Pfizer uses AI algorithms to improve efficiency of procuring raw materials, predicting disruptions in their supply chains and also increase the volume and efficiency of production which can in turn increase drug availability. This aligns with survey results as besides regulatory compliance, supplier coordination, improved logistics and also faster production cycles were identified as the main drivers of drug availability through AI also leading to high estimated of stockout decreases. Another example from the academic literature which aligns with survey results is Merck which uses AI to create simulations with which they optimize production cycles and decrease downtime and disruption (Hemamalini et al, 2024). Literature also suggests AI powered machine learning used in pharma to monitor real time data from warehouse sensors to improve the efficiency and optimize inventory levels contributing to decreases in stockout (Guo, 2023).

Improved logistics were also identified as a major way to increase drug availability and literature supports that through a specific example of UPS and drone manufactures Zipline, collaboration, to improve last-mile delivery with AI powered autonomous drones in Africa. Decreasing the times from firm to patient and decreasing spoilage providing an important solution which raise availability in constrained environments (Dash et al, 2019).

Literature suggests that AI is used for improving regulatory compliance through natural language processing models which analyse vast amounts of data and extract key information helping with regulatory submissions. AI also improve compliance through Automated document management which help prepare and submit regulatory documents which improves time and efficiency. Finaly it is also reported to use machine learning to make predictions and decisions on regulatory topics without being programmed for each new task. Literature shows that all of these are being used in many industries, however, do not explicitly name PSCs (Boopathi & Raja, 2024; Ajegbile et al, 2024). All of these uses could majorly help drug availability as every part of the PSCs are heavily regulated. This information does not align with survey results as enhanced regulatory compliance is indicated most frequently as the main driver for drug availability. An explanation could be that at the time of literature research the aforementioned technologies were beginning to be used in the pharmaceutical sector and are now one of the most prominent.

Overall, the literature and primary data align only partly. With the literature review suggesting a lot of potential for AI to improve drug availability, while survey results suggest

that AI is already substantially improving drug availability, mainly through enhanced compliance and logistics. Literature also does not observe tangible stockout reductions, while primary data shows estimates are moderate to high. This would imply that the potential uses of AI examined in the literature are already being adopted in real life and are currently showing tangible benefits in pharma companies. Which provides real examples answering RQ2. Primary data results would suggest that AI's role in improving drug availability is largely indirect, as regulatory, logistics and supplier enhancements reduce the likelihood of disruptions, they do improve drug availability but not directly through increased productivity.

3.6 Barriers, Risks, and Future Outlook

While survey results showed great optimism about the role of AI in improving cost efficiency and drug availability, participants also pointed out a number of risks or barriers that affect adoption or implementation. Most frequently cited were lack of clear ROI and data quality issues. Lack of budget, resistance to change and the ever-evolving regulatory challenges were also highlighted as an important-to-address barriers. The results suggest that while AI is widely perceived as beneficial for PSCs, the integration of it within pharmaceutical companies remains challenging. Similar risks were also identified in the existing literature.

Regulatory complexity is an identified risk that aligns well with literature, which consistently highlights the highly regulated nature of the pharmaceutical industry as a barrier for its digital transformation and adoption of AI. The need to follow many different regulatory bodies which govern different areas of operation makes it even more challenging (FDA,, 2025; WHO, 2019; EMA, 2025). AI processes vast amounts of data in order to contribute to the area where it is used, regulatory bodies also require robust privacy systems as information that AI can processes in pharmaceutical companies is highly confidential. These requirements further highlight the regulatory challenges as an important barrier to AI adoption (Schmidt et al, 2020). Data quality and availability was also identified in the survey as a major challenge, Vellanki, (2024) highlighted the importance of pharma companies following the ALCOA standard which are data integrity standards specific to the industry, for collecting, using and keeping dana according to the regulations. It is worth pointing out that regulatory compliance was one of the main identified areas where AI is used and positively affected, which indicates that barriers connected to regulations may already be combated with AI, while complying with the dana integrity standards.

While literature emphasized, regulatory issues, building of trust readiness of the firms when it comes to educating the workforce, data readiness, data privacy and cybersecurity, the survey results highlighted uncertainty about return on investment and lack of budget for implementation of AI (Vellanki, 2024; Schmidt et al, 2020; Ismael 2024). This would suggest that financial justification of AI is an equally strong concern as the regulatory, privacy and data issues pointed out by the literature. The survey here contributes and additional perceptive when it comes to barriers, which should be investigated further.

Another major barrier identified in the survey was resistance to change and company culture, which was not directly stated in the literature review, however there are factors mentioned which could support this. For example, Schmidt et al, (2020) highlighter trust and transparency as important factors when it comes to AI technologies, and educated stakeholders are pivotal to this. Having to change the way of processing data and educating a large number of people could be a contributing factor of resistance. Bureaucracy surrounding this sector which can lead to substantial fines and bans could contribute to this cultural resistance to adoption of new technologies.

Despite these barriers the survey also revealed an optimistic outlook for the future. When asked to identify potential areas which could benefit from AI in the future, most frequently cited were the recurring regulatory compliance and sustainability. This is consistent with the literature as it puts emphasis on reducing waste and environmental impact of pharma industries in the future as well as increasing transparency and sustainability through ethical sourcing of raw materials. These findings suggest a shift towards focusing on more sustainable and earth-friendly supply chains also in the pharmaceutical industry. Additionally, the majority of respondents indicated their companies are likely or very likely to increase adoption of AI in the next 3 years. A mean rate (1-5) was 4,22 with SD of 0,8 which confirms the consensus when it comes to future adoption. And with innovations implementing AI such as, autonomous vehicles with path planning, intelligent cameras and even drones for last mile delivery; AI powered robots for warehousing optimisation and Generative AI systems for regulatory submissions the literature does support the finding in the results. The use of AI in PSCs is becoming and will continue to become a notable strategy for improvements. (Chui et al, 2018; Bathla et al, 2022; Shah et al, 2024).

In sum, the finding reveals two side, while professionals in the industry recognize the benefits AI can bring to cost efficiency and drug availability, they also highlight that they face barriers which complicate implementation. Regulatory complexity and data integrity are barrier which align closely with previous research, while financial justification and budget

concerns emerge as more prominent in the survey result than in literature. While there are connections to be made from literature supporting culture and resistance to change as another important risk it was also more prevalent in the primary results. All of these examples tie directly to RQ3. At the same time results show strong optimistic outlook for the future implementation of AI. These insights implicate that while AI is on a positive trajectory, but in order for firms to increase their adoption in the future, they will have to navigate persistent barriers and risks which need to be navigated and mitigated.

3.7 Theoretical and Practical Implications, Limitation and Future Research

3.7.1 Theoretical Implications

The finding presented in this study provide several contributions to the academic research of AI in pharmaceutical supply chains. They observe and reinforces existing evidence on the challenges which PSCs are facing. Regulatory compliance, cold chain logistics, distribution costs and demand forecasting were consistently highlighted by both primary research and existing literature, emphasizing the complexity and highly regulated nature of the pharmaceutical industry (Mentzer et al, 2001; Vaittinen, 2016, Infosys, 2020). The study supports the view that PSCs face unique, industry-specific, challenges which shape both the challenges and urgency of AI adoption as a solution.

Second, the study extends the literature by showing demand forecasting as major challenge almost as prevalent as regulatory and cost related concerns. While it has been also mentioned in the literature as a challenge (Moosivand et al, 2017; Merkuryeva, 2019) the respondents gave much more emphasis on it also identifying it as one of the areas where AI is currently being used. This suggest that the challenge is identified as a major one and is already being addressed by AI innovations. This would indicate a shift for academic discussion where more wight should be given to demand forecasting as a challenge of PSCs alongside the traditional ones.

The study also contributes novel insights when it comes to the barriers and risks to AI adoption. Literature strongly emphasized regulatory and data integrity issues (Schmidt et al, 2020; Vellanki, 2024), the survey respondents identified concerns with return-on-investment and lack of budget as equally pressing risks. These, more financial risks are less researched in existing literature, suggesting that future academic research should pay more attention to

economic justification of AI implementation, especially when it comes to highly regulated industries such as the pharmaceutical. Resistance to change and cultural concerns were also underrepresented in literature but were another major concern from survey participants, suggesting these concerns might be more influential when it comes to adoption of AI than current academic research acknowledges.

Additionally, survey results show quite optimistic estimates of cost reduction and decreases in stockouts with tangible numbers. The numbers are less frequently found in the literature suggesting that direct and tangible benefits resulting from AI adoption are not research enough or have not yet been observed by academic literature (Chui et al, 2018; Shah, 2024). Primary data adds a layer of real industry results which need to investigate further to build on the results and show more proof of positive results.

Finally, the results also contribute to the connection between new technologies and sustainability. Respondents identified sustainability as one of the main areas potentially benefiting from AI in the future. This is complemented by literature which suggests sustainability and ethical sourcing as important challenges to address Heim et al, 2023; Bengtsson, 2023). AI has the potential to contribute to combating growing environmental concerns and is a topic worth investigating further, contributing to already existing theory.

Overall, the study doesn't just confirm many observations from existing research but also expands the theoretical debate by calling attention to underexplored or even new factors, including financial and cultural barriers to adoption, the growing need for forecasting and sustainability. With this, it provides a more detailed understanding of how AI is positively impacting PSCs and calling attention to areas which need to be investigated further and built upon.

3.7.2 Practical Implications

The results of this study offer many insights for managers, policymakers and other stakeholders. Firstly, the strong role of regulatory compliance, both as a challenge and also an implementation area, suggest that managers should priorities tool which support monitoring, documentation and privacy in order to comply with regulations and be able to adopt AI in the most efficient ways. This can lead to less compliance related issues and also strengthen the collaboration and trust with the policymakers.

Second, the recurring emphasis on demand forecasting as an important challenge and future area for adoption, indicates that investing in predictive AI tools could deliver important

benefits for reducing stockouts, over-stocking and making logistics much more efficient. Policymakers could also encourage sharing of anonymous data about demand across the industry in order to build more effective prediction models where the industry could benefit as a whole.

Financial concerns, such ROI and high costs, were highlighted as a major barrier by the survey. Pharma leaders should focus on developing clear business cases which show measurable data on costs of implementing AI solutions and also document outcomes such as reduction of distribution costs, stockouts and compliance violations in order to give a quantifiable example for other firms wanting to adopt AI. AI solution providers could offer systems which showcase the benefits in real numbers and can be adapted to company sizes and their needs. This way they could address financial concerns early.

Finally, as culture and resistance to change were highlighted, managers and also regulators should strive towards educating, training and informing all key stakeholders when implementing a new w solution. As trust and transparency is an important way to bridge the resistance and open the doors for adoption. This is important because the survey highlighted how AI will continue to play a growing role in the following years.

Sustainability will be important for the future as the survey and literature suggest. Manager and other leaders in the industry should strive not only towards reducing cost and improving drug availability, but also following environmental and other sustainable initiatives, which would create a positive image of them and build trust with their stakeholders. Policymakers should set incentives to promote sustainable practices through AI adoption.

By addressing the aforementioned financial, trust, education and regulatory challenges and leveraging current benefits, pharma companies as well as other stakeholders can maximise the potential benefits AI brings to their supply chain while ensuring compliance and sustainability.

3.7.3 Limitations

While the study provides valuable insights around the adoption of AI in PSCs, limitation also need to be acknowledged. Data is based on a survey with 111respondents. Even though the sample size is sufficient for descriptive analysis, it does limit generalisability of findings, especially when it comes to different firm types within the industry and geographical regions. The sample may be subject to bias as the target sample were workers within supply chains, this could cause prioritization of some challenges, where broader strategic or financial considerations were not mentioned. Also the sample was quite heavy on regulatory compliance roles, which could point to some bias in asnwers.

While results included all regions as main markets of respondents' firms, the majority reported Euro, Asia and North America as the main regions. Which could harder generalisation globally, as different regulations, digital maturity and infrastructure could be factors. The survey also showed nuances by company size, but bias can also exist as smaller companies may exaggerate their level of adoption to appear more technologically mature and ready.

As the study was based on a survey the results present perceptions rather than direct data of performance. Respondents reported cost reductions, for example, could not be verified again real financial records of firms. This is important to consider when we compare actual data provided by real world business cases.

Finally, challenges, risks and benefits were observed in detail, it is hard to capture contextual details that can influence adoption. Comparisons could be done by company size, professional experience of respondents, but regulatory environments, company culture and similar factor could not be measured and can still influence the adoption processes. These would require case-based approaches for deeper exploration.

3.7.4 Future research

The limitations of this study open several opportunities for further research on the topic. Research could expand the sample both in size and scope. A larger dataset including more representation of high executives, finance, R&D and policymakers, to help capture a broader and more balanced view also from a strategic and financial side as well as view from outside of the organisations. Underrepresented regions should be included to widen the global reach of the study.

Further studies should add case studies and qualitative in-depth research methods in order to capture richer insight into how and where AI is implemented in practice while taking into account organisational culture, regional influences and other factor which may be less visible in this study and can still influence adoption.

Due to the rapidly evolving technology and also changing of the environment in all industries, longitudinal research is needed in order to follow changes and adoption trends over a period of time. Results from primary research may already be reflecting recent changes and benefits while the literature is still trying to catch up with actual data. By following the same or similar sample across several years, valuable insight could be gained observing changes in optimism or outlook, adoption level and benefits or risks over a longer period of time.

Finally, future research should investigate the financial and economic factor of AI implementation more in-depth. To understand return on investments and observe realistic number of cost reduction or stockout reduction as AI becomes more prevalent. This could provide managers and potential adopters with clearer benchmarks for how to evaluate if AI projects are feasible for their firms.

3.8 Summary of Discussion

This chapter interpreted the survey finding, tying them to existing literature. The results confirmed existing challenges of PSCs such as regulatory compliance, logistics and distribution costs, while highlighting demand forecasting as a growing need. They highlighted that AI innovations is becoming widely adopted, even more than literature would suggest. Even with this, the results observed barriers and risk related to adoption, such as financial implications, regulations and cultural resistance.

The discussion provided both theoretical contribution, such as, underexplored financial concerns and results related to adoption of AI. And also, practical contributions by bringing attention to sustainability issues' potential to be addressed by AI. Limitations of scope and method were also acknowledged providing suggestions for further research.

In sum, the findings show an industry which has more recently began rapidly adopting new technologies, which are currently already showing tangible benefits, which do need to be further researched for deeper insights. While optimism towards current AI adoption and its future seem to be the main theme, professionals show maturity by acknowledging barriers and risks which need to be addressed if the sector wants to follow adoption trends in the future.

Conclusion

To summarize it all, this study researched the effect of artificial intelligence (AI) innovations on pharmaceutical supply chains (PSCs). The research combined the review of current literature and a structured survey of industry professional (n=111) in order to answer 4 research questions connected to cost savings, drug availability, existing implementation and risks and barriers to implementation of AI in PSCs. All of them were addressed extensively through results and discussions.

Main empirical findings showed the following: related to RQ4, AI adoption is already common and widespread among sample organisations with 84 respondents (around 76%) reported already using AI within their supply chain operations, with higher rates among medium-sized firms. Withing these adopting organisation AI is applied most frequently in regulatory compliance, manufacturing and logistics optimisation, and respondents perceive these as positively impacted. Perception of AI's impact on cost efficiency and drug availability were highly positive with respondents giving high ratings that AI reduced operational costs (mean=4,35, SD=0,65) and improved drug availability (mean=4,43, SD=0,57). Respondents from adopting organisation also reported measurable reductions of costs and stockouts, connecting directly to RQ1 and RQ2. Despite the general optimism participants highlighted substantial risks and barriers. Addressing RQ3, besides the traditional regulatory concerns, they pointed out ROI concerns and budget limits as a major risk which was underreached by the existing literature. Sustainability was identified as the main potential beneficiary, contributing to the future outlook. High estimated benefits and a generally positive view while still acknowledging the risks, were the main theme of the study.

The empirical results make important contributions both theoretically and practically. While the study confirms many established insights about the complexity, regulatory and logistical constraints of the industries' supply chains two important consideration for future research emerged: financial justification and organisational culture and resistance to change. This shows that the thesis highlights all different factor which may influence the adoption of AI innovations such as culture and finance and not only the widely researched regulatory and technical factors. Practically, it brings attention to managers to build clear business cases observing tangible cost and benefits in order to create a clear benchmark of what is feasible and beneficial to the firms in the economic matter. It also highlights the clear importance of education and communication of change within companies. The study also suggest that

regulatory bodies may help adoption and digitalisation by clarifying compliance expectations and providing frameworks for data sharing which preserves privacy and anonymity.

The methodology of the thesis demonstrates the value of targeted surveys for understanding challenges specific to an industry over a range of different roles. However, interpretations of the results need to take limitation into consideration, self-reported perceptions, concentration around certain roles and geographical markets are an example of that. These limitations make openings for further research. Further studies should focus on combining broader surveys with real financial and drug availability metric. Adopt longitudinal approach in order to follow the fats changing environment. And finally, research case studies of real examples of AI projects which may already be available for research soon, seeing the widespread adoption.

From findings and observations a few concrete recommendations emerge: **First**, form firms and managers withing supply chains, invest in outcome-oriented pilots for demand forecasting and sustainability tracking, these can demonstrate measurable saving and benefits and can be built upon and expanded if shown to be beneficial. Invest in educating and upskilling the workforce and provide full transparency with major stakeholders such as policymakers to build trust. **Second**, for AI solution providers: offer scalable models for specific areas, with clear pricing and a clear map for implementation and expended performance so the firms can evaluate the feasibility of implementing your solutions. **Thirdly**, policy makers should clarify regulatory requirements that are related to AI and its adoption in PSC functions. They should support initiatives for anonymous data sharing of demand data in order for the industry to benefit as a whole and ultimately the patients benefiting, as the business is about saving lives. These recommendations are meant to reduce the barriers and help combat challenges faced by the entire industry harmoniously, while maintaining competition.

In conclusion the adoption of AI in pharmaceutical supply chains is a rapid but cautious progression. Firms are increasingly embracing AI as a tool to combat challenges related to compliance, forecasting and logistics and are having a positive reaction to these implementations. At the same time the industry remains cautious due to barriers connected to budgets, cultural resistance and regulations. The thesis shows that the industry is optimistic about the current and future benefits of AI, while remaining realistic about the risks it may face and the hard work it needs to put in to overcome them and efficiently bring critical healthcare to patients worldwide.

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Appendices

Appendix A: Survey Questionnaire

Masters Thesis Survey - MiM

Hello! My name is Niko Petrović, and I am currently writing my master's thesis at ISCTE Business School and SEB LU, University of Ljubljana in the International Management and IMB program. In this short survey I want to research the role and impact of artificial intelligence (AI) in pharmaceutical supply chains.
Your answers are **completely anonymous** and will be used solely for academic research purposes. Completing the survey should take approximately **4–7 minutes**.

Thank you very much for your valuable contribution to this research!

1.

Do you agree to participate in this survey, knowing that your responses will remain confidential and be used solely for academic research?*

Označite samo en oval.

Yes, I agree
No, I do not agree

Background information

2.

What is your current role?*

Označite samo en oval.

Supply Chain Manager
Procurement Specialist
Manufacturing/Production Manager
Logistics/Distribution Manager
Regulatory Affairs Specialist
IT/Data Analytics Specialist
Drugo:

3.

How many years of experience do you have in the pharmaceutical industry?*

Označite samo en oval.

Less than 2 years
2–5 years
6–10 years
11–20 years
More than 20 years

4.

What is the size of your organization?*

Označite samo en oval.

Small (fewer than 50 employees)
Medium (50–250 employees)
Large (more than 250 employees)

5.

Which region does your company primarily operate in? *(Select all that apply)**

Izberite vse primerne odgovore.

Europe
North America
Asia
Africa
South America
Australia / Oceania

Current use of AI

6.

In your opinion, what are the biggest current challenges facing pharmaceutical supply chains? (Select up to 3)*

Izberite vse primerne odgovore.

Demand forecasting accuracy
Inventory and stock management
Cold chain logistics and temperature control
High cost of distribution
Regulatory compliance
Ethical sourcing and sustainability
Drugo:

7.

Is AI currently used in your organization’s supply chain processes?*

Označite samo en oval.

Yes

Preskočite na vprašanje 9

No

Preskočite na vprašanje 8

Neimenovan razdelek

8.

Are there plans to implement AI in the next 2 years?*

Označite samo en oval.

Yes
No
Not sure

Preskočite na vprašanje 17

Neimenovan razdelek

9.

In which areas is AI currently used? (Select all that apply)*

Izberite vse primerne odgovore.

Demand forecasting
Inventory management
Logistics & distribution
Manufacturing optimization
Regulatory compliance
Sustainability tracking
Drugo:

10.

Which areas of the supply chain, in your opinion, have already been positively impacted by AI?*

Izberite vse primerne odgovore.

Demand forecasting
Inventory management
Logistics & distribution
Manufacturing optimization
Regulatory compliance
Sustainability tracking
Drugo:

11.

On a scale of 1–5, how much do you believe AI has reduced operational costs in your organization?*

Označite samo en oval.

No impact
1
2
3
4
5
Very high impact

12.

Which cost-related areas have benefited most from AI? (Select up to 3)*

Izberite vse primerne odgovore.

Labor costs
Transportation/fuel costs
Inventory holding costs
Waste/spoilage reduction
Regulatory compliance costs
Procurement & sourcing costs
Drugo:

13.

What estimated cost reduction have you observed or recorded due to AI implementation?
*
Označite samo en oval.
Less than 5%
5–10%
11–20%
21–30%
More than 30%
Not applicable / Unknown
14.
On a scale of 1–5, how much has AI improved drug availability in your supply chain?*
Označite samo en oval.
No significant improvement
1
2
3
4
5
Very significant improvement
15.
If possible, please estimate the percentage decrease in stockouts since AI adoption.
*
Označite samo en oval.
Less than 5%
5–10%
11–20%
21–30%
More than 30%
Not applicable / Unknown
16.
Which factors have contributed most to improved availability through AI? (Select up to 3)*
Označite samo en oval.
Faster production cycles
Improved logistics & distribution
Improved supplier coordination
Enhanced regulatory compliance
Other (please specify)

Neimenovan razdelek

17.
Has your organization implemented AI in their operations outside of supply chain?*
Označite samo en oval.

Yes
No

18.

If applicable, where did the organization apply AI outside of the supply chain?

19.

What are the main barriers to AI adoption in your experience or opinion? *(Select up to 3)*

*

Izberite vse primerne odgovore.

Lack of budget
Lack of in-house expertise
Data availability or quality issues
Regulatory or compliance concerns (e.g. GDPR, HIPAA)
Resistance to change / organizational culture
Lack of clear ROI (Return on Investment)
Integration with existing systems
Drugo:

20.

In which areas do you see the greatest potential for AI in the future?*

Označite samo en oval.

Demand forecasting
Manufacturing optimization
Logistics/distribution
Regulatory compliance
Sustainability tracking & ethical sourcing
Other (please specify)

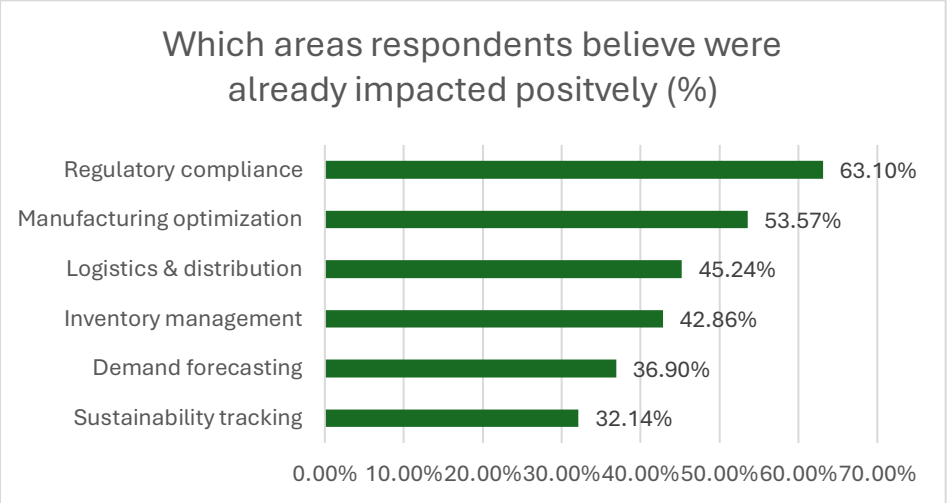
21.

On a scale of 1–5, how likely is your organization to increase AI adoption in the next 3 years?*

Označite samo en oval.

Not likely
1
2
3
4
5
Very likely

Appendix B:



Appendix C:

