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Mapping Waste in a Clinical Supply Chain

Bachelor's thesis in Industrial Management and Production Engineering

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PREFACE

This thesis work was conducted during the spring of 2024 as a part of the program Industrial Management and Production Engineering at Chalmers University of Technology. The project was carried out on the premises of AstraZeneca Gothenburg where there were possibilities to communicate with other sites within AstraZeneca such as in the United Kingdom and United States of America. Two students conducted this thesis as the course consisted of 15 credits. Mapping waste during a clinical supply chain is the focus of this thesis and the scope of the project was created between students and supervisors from both AstraZeneca and Chalmers.

Firstly, a huge thank you to both of our supervisors. First and foremost, our supervisor and examiner from Chalmers, Patricia van Loon, who consistently provided guidance, feedback, and encouragement throughout the entire project. Her knowledge from working within the Supply and Operations Management at Chalmers was invaluable during the process of writing the thesis.

Secondly, the supervisor from AstraZeneca, Marcus Josefsson, was a pillar during this project with his industry knowledge and emotional support. Marcus has continually been very generous with his time while being very engaged in the writing process. Functioning as a mentor guiding us and facilitating contact with interviewees while introducing us to his team. This project would not be possible without Marcus' help as he consistently guided us throughout this project. A massive thanks to Marcus Josefsson, his colleagues and all of AstraZeneca.

Finally, a dedication to our interviewees. They have generously shared their time, thoughts, and knowledge and for that they have our deepest thanks.

Key words: Waste, Clinical Supply Chain, Sustainability, Clinical Trial/Study, Expiration Date, Labelling

Abstract

This thesis examines the generation and management of waste in the clinical supply chain of AstraZeneca, with a specific focus on the sustainability challenges inherent in clinical trials. Despite the growing emphasis on sustainability in healthcare and biotechnology, the clinical supply chain has received less attention compared to the commercial supply chain. This research identifies key areas within clinical trials that contribute to unsustainability and proposes methods to mitigate waste and enhance ecological and economic sustainability. The study utilizes a mixed-methods approach, combining a literature review with qualitative interviews conducted with employees directly involved in AstraZeneca's clinical supply chain. This methodological approach helps to map out the waste production points within the study supply chain and identify factors contributing to waste. The findings indicate that significant waste occurs due to factors such as forecasting inaccuracies, communication challenges, and inefficiencies in labelling and packaging processes. By providing a detailed analysis of waste generation in a crucial but understudied area of pharmaceutical operations the thesis will contribute to and expand the field. It suggests that improving forecasting accuracy, enhancing information channels, and adopting innovative labelling solutions like digital labelling could significantly reduce waste. This research supports the development of more sustainable practices within the pharmaceutical industry, promoting not only environmental benefits but also operational efficiencies.

Innehållsförteckning

1. Introduction

The clinical supply chains of today are facing tremendous adversities with regards to waste accumulation. Estimates suggest that clinical trials on average scrap as much as 70 percent of drugs manufactured for aforementioned trials (Coppe, 2023). This not only poses huge environmental implications, but is also of financial concern. The cost of logistics in the healthcare field is about 38 percent of total costs according to one study, this is compared to other fields such as the electronic industry who have costs as low as two percent of total costs (Kwon et al., 2016).

Due to these challenges sustainability is increasingly prioritised within the healthcare and biotechnology sectors (Bendelac, 2023). Despite this increasing awareness, the clinical supply chain is much less researched and analysed as opposed to the commercial supply chain. Addressing this awareness gap is essential in advancing sustainability objectives. This thesis will examine key areas within clinical trials that pose challenges to sustainability efforts. Further, it will propose practical steps that clinical supply chain operators can take to enhance sustainability and promote eco-friendly practices in bringing vital medicines to market. As the findings of Coppe (2023) clearly suggest, a significant challenge within the clinical supply chain is the amount of drugs scrapped and therefore this type of waste has been investigated in the thesis.

The World Health Organization (WHO) defines pharmaceutical waste as undesirable pharmaceuticals, which include expired, unused, spilled and infected products, which should be disposed of (WHO, 1999). The increase of waste has resulted in a need to research clinical supply chains (Hui et al., 2020), to understand the importance of minimising waste and become more sustainable.

In the clinical supply chain, there is a large emphasis on achieving time and quality goals. This is considered difficult to uphold as the research and development (R&D) industry has become more complex (Kachwala et al. 2021). This stems from a combination of strict regulations, high importance of maintaining reputation, as well as large costs being associated with delays in the start of trials (Kachwala et al. 2021). However, this is often accomplished at the expense of large costs and amounts of waste which is problematic from a sustainability perspective. An issue that affects quality and sustainability is deviation among packaged and labelled kits, which then go to waste (Kachwala et al. 2021). This highlights the industry's difficulties with having to maintain high quality standards, often leading to the disposal of products that fail to meet these requirements.

It has been argued that achieving sustainability goals encompassing environmental, social, and economic has transitioned from being a lofty ideal to an economic

necessity for the pharmaceutical industry to sustain its current pace of innovation (Newton, 2023). Therefore, it is necessary to understand why waste is generated and how it can be minimised.

1.1 Problem Description

This thesis will investigate the sustainability challenges in the clinical supply chain of AstraZeneca, focusing on minimising waste. Clinical supply chain in this context refers to the process of supplying clinical trials with the medicine under the investigation of the aforementioned clinical trial. The investigation will focus on the latter stage of the supply chain, called the study supply chain where distribution to customers is central, see image 1 below. There are large amounts of waste accumulated in Astrazeneca's supply chain, early interviews suggest upwards of 50% of all medicine produced for clinical trials is scrapped.

The Clinical Supply Chain in AstraZeneca's research and development can be divided into two sections. These two sections are the "Programme Supply Chain" and the "Study Supply Chain".

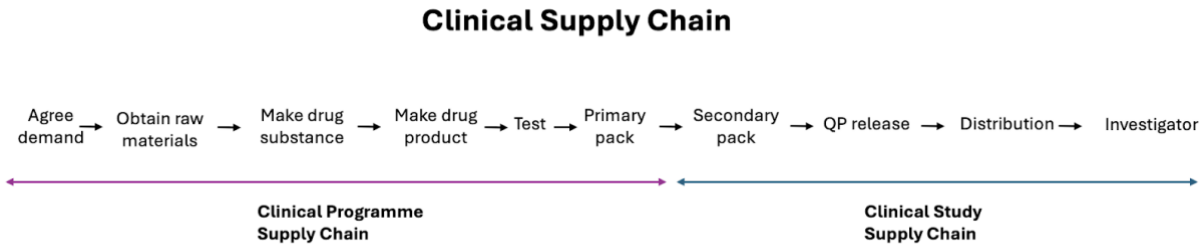

Figure 1: *The stages of the clinical supply chain. This study will focus on the latter part, known as the study supply chain*

The "Progamme Supply Chain" covers all activities to manufacture a Drug Substance, which is the active compound to be studies, and to formulate this into a Drug Product that can be used for patients in different clinical trials. The Drug Product could be in the form of a liquid for injection, a capsule or tablet, a powder for inhalation or other. The Progamme Supply Chain ends with the primary packaging step, which gives the Drug Product its initial cover. The primary packaging could be a vial, bottle, blister card or other. The next step in the Clinical Supply chain is the secondary packaging which includes labelling of the product. In the labelling step information specific for a clinical trial is added to the product according to local regulatory requirements. Up to the primary packaging step, clinical trial material could be manufactured and used for multiple trials. But when performing the secondary packaging and labelling step, the clinical trial material becomes study specific and can only be used for that specific study. That starts the "Study Supply Chain" which

end with distribution of the clinical trial material to an investigator site where the investigational drug can be administered to patients as per the study protocol.

In the “Study Supply Chain” there is less flexibility in re-purpose. The discovery of significant waste generation throughout the study supply chain has led to the restriction of the thesis to this specific area. Another reason for study supply chain to be used as a focus area is because there were several more possible interviewees within this area. Utilising the study supply chain is also beneficial due to its finite timeline, concluding upon the enrollment of patients.

Currently, there is an objective from AstraZeneca to reduce waste within the clinical supply chain to increase product sustainability (AstraZeneca, 2023). Achieving this requires a comprehensive understanding of the sources and underlying causes of waste. Difficulties arise where big changes are wanted, yet clear definitions of problematic areas are lacking.

1.2 Purpose

The aim of this project is to map where waste occurs within the study supply chain process and identify the factors contributing to its occurrence. This will facilitate the development of future strategies within AstraZeneca aimed at reducing waste to create a more sustainable clinical supply chain.

1.3 Research questions

The thesis seeks to answer the following questions:

- At what points in the clinical supply chain, within the study supply chain, does the majority of waste occur?
- What are the most common contributing factors to increased waste at the level of a study?
- What could be done to alleviate some of the contributing factors?

1.4 Limitations

This study will primarily be limited to Study supply chain, and not programme supply chain. Study supply chain is based on taking a finished bulk product, and packaging and distributing the same product to be study specific, whereas Program supply chain’s scope is the acquisition and manufacture of a bulk product.

The study will mainly focus on environmental and economic aspects of sustainability, and more specifically it will focus on scrapping of products as a proxy-measurement for environmental impact.

The selection of studies will be small due to time constraints and complexity of the questions, and therefore might be less representative.

2. Method

The purpose of this chapter is to describe how the study was conducted and the methods used. It also seeks to describe the central elements of the study, as well as the order they were performed in.

The approach employed during the project has been iterative; as new empirical discoveries were made during the project, theories and other project components were reconsidered such as lean manufacturing regarding waste in the supply chain (Dubois, & Gadde, 2002). The reason for this is based on the notion that the analysis, and thus the need for specific theories, evolves as new empirical evidence is discovered. Therefore, it simplifies that work be conducted iteratively and that theory and empirical data can evolve together. This approach was chosen because the authors anticipated that new, interesting empirical data would emerge during the interviews, which, in turn, would require new theoretical foundations. The theoretical framework mostly concerned lean manufacturing, supply chain management and sustainability.

The sources used during the study articles collected through the Chalmers Library, through google scholar or internal data given at AstraZeneca.

2.1 Literature Study

The literature review in this project served several distinct functions. 1) to establish a general understanding of and lay a theoretical foundation for the various subject areas covered in the report and, 2) to critically evaluate responses and assertions from the interviews conducted. Additionally, methodological literature was consulted to identify appropriate approaches for conducting the work, such as guidance on conducting interviews in the most effective manner. The reason why literature study was used was because there was already existing foundational information regarding the matter. To answer the research questions, already existing sources such as academic papers regarding sustainability challenges in the clinical supply chain, were used as a starting point for new inquiries within the field. To find good sources in the initial part of the research, key words correlated to “Clinical supply chain”, such as “Lean manufacturing”, “Waste”, and “Sustainability” were used in the search. These led the search to more specific topics such as “Shelf Life” as new information was found through the foundational interviews.

Primarily, the literature review is based on scholarly articles or other sources subjected to peer review or similar fact-checking mechanisms. When searching for articles, approximately 100 000 articles discussed the matter, but only around 35 were used but several more were reviewed to see if they would be useful. The selection of articles was based on the theme of the text and whether it was suitable information to base the foundation of the project. For example, previous studies

discussing waste within clinical supply chains were used as a guidance. No specific selection criteria were applied to filter relevant literature. For instance, articles of any age were used, as the study's theory, among other aspects, seeks to delineate historical development. Additionally, articles written in both Swedish and English were included, with no distinction made based on the articles' country of origin.

2.2 Interview Study

The main method that was used to answer the research questions was collecting data through interviews. The primary reason for this is because the needed information for the research cannot be found using questionnaires. The reason for this was because interviews provide opportunities to attain more in-depth information compared to questionnaires (Kairuz et al., 2007). Questionnaires often show simple and short answers gained from multiple choice questions or open questions. Additionally, questionnaires were not used because the authors could not form multiple choice questions, since there was no previous knowledge regarding what the multiple choices should have involved. Surveys were considered as a method as it can consist of both quantitative research strategies (e.g. questionnaires) and qualitative research strategies (e.g. open-ended questions) (Ponto, 2015). Nevertheless, surveys intend to find a specific pattern through a population, such as understanding where in the supply chain waste was generated (Merriam & Tisdell, 2015). The problem with surveys was that the answers that it would give would not be sufficient, meaning that specific follow-up questions could not be asked if a survey was used.

Therefore, interviews gave sufficient answers and the ability to ask direct follow-up questions based on the interviewees previous answers. The usage of interviews enabled the interviewees' perception more deeply since it gave more ambiguous replies that could be clarified at the point of the interview. Since this was not an experimental study, there was no usage of a questionnaire since there was no sample size to be calculated. Using five to 10 interviewees was sufficient to gather the information needed to proceed with the project (Kairuz et al., 2007).

Interviews help understand the issue from the subjects’ perspectives, which in this case tells what problems occur during a clinical supply chain regarding waste (Mann, 2016). These interviews were carried out with employees at AstraZeneca who work closely with the clinical supply chain. To enable gaining answers to the research questions, interview questions were formed because of the literature study. The interview questions were formed by exploring what subjects could be useful when searching for answers to the research questions. This knowledge was mainly collected from the literature study through research from online resources, like scientific articles, and academic books that suit the subject, using the keywords mentioned before. In the beginning of this process, interviews were more spontaneous since the initial data was collected from employees, referred to in this

thesis as “Foundational interviews”. These foundational or pilot interviews enabled the formation of the interview questions used when answering the research questions. During these pilot interviews, interviewees were given the opportunity to discuss their knowledge, thoughts, and feelings concerning the matter (Launso, 1991).

Interviews were used since it is an effective way to attain more specific information regarding the research questions (Patel, 2011). It is important to inform the person being interviewed why they are being interviewed and what their knowledge will bring to the thesis. Secondly, it is necessary to point out during the session what information is confidential and what is not. All this information was given at the beginning of the session so that participants know the purpose of the interview. This was accomplished by discussing ethics, rights and explaining the purpose of the interview in the invitation to the interview, which was sent out through email. Another important factor to consider is the impact of personal relationships between interviewers and interviewees on motivation levels. As interviewers, it is necessary to convey genuine interest and understanding to ensure that the interviewees feel heard and valued. Consequently, the focus of the interviews is solely on gathering information from AstraZeneca employees, rather than sparking debates (Patel, 2011).

The research adopted a qualitative approach (Lind, 2019). Qualitative research is a way of studying a subject through specific interest groups, where the researchers are interested in interpreting their experiences within the subject (Merriam & Tisdell, 2015). Qualitative research was used since the project intended to understand and interpret the experiences AstraZeneca employees had with waste generated in the clinical supply chain. The objective was to answer the research questions discussed in the introduction, which was primarily to demonstrate the occurrence of waste while also explaining the specific areas where these issues arise.

Based on this method, empirical evidence can be generated according to the research questions and theoretical framework of the study.

2.2.1 Interview Process

The interview questions were sent to each interviewee at least two days in advance. This provided the interviewee with the opportunity to prepare answers to the questions and to search for information they do not possess themselves, such as by discussing the question with a colleague. All interviews were conducted by the two authors. During each interview, one author was designated to take a more active role and lead the interview by asking questions. The other author participated sporadically in the discussion but was focused on taking notes and acting as secretary. The interviews were pursued for about an hour and was conducted as an online meeting

through “Microsoft Teams”. Further details regarding the scheduling of the interviews is available in appendix II.

2.2.1.1 Interviews Pursued Through Microsoft Teams

The reason for online meetings being used was because most interviewees were in either the United Kingdom or the United States of America. There were also interviews conducted with interviewees from Sweden, but these were also conducted via Microsoft Teams. This ensured equal opportunities for everyone when answering questions and reduced the likelihood of answer variations due to different interview formats.

Online interviews were primarily conducted since they enable contact with interviewees without having the need of transportation (Salomons, 2009). It also enables an increased number of interviewees since the people working with the clinical supply chain were geographically dispersed (Ahern, 2005). Online interviews also increased the comfort of the interviewee since they were able to perform the meeting in an environment that they felt comfortable in, which enabled discussions about more sensitive matters such as emotions regarding waste in the clinical supply chain (Cabiria, 2008).

2.2.1.2 Choice of Interviewees

The interviews were carried out with employees at AstraZeneca who work closely with their clinical supply chain and had primarily a role where they lead studies from a supply chain point of view. All of those interviewed have previously been a part of different studies, both closed and ongoing, and could therefore bring useful information regarding the mapping of waste in the supply chain. The interviewees were professionals responsible for coordinating supply chain activities for a specific study, associated with studies with large amounts of waste. The objective was to secure interviews with 5-10 individuals, the authors managed to connect with six.

2.2.1.3 Form and Structure of the Empirical Interview

The method used when performing interviews were semi-structured interviews, where the questions were predetermined, and all candidates were asked the same questions in the same sequence (Galletta & Cross, 2013). See appendix I for the questionnaire. Semi-structured interviews were a preferred course of action for data collection as researcher’s goal was to understand the interviewees unique perspective on the matter, rather than a general comprehension (Adeoye-Olatunde & Olenik, 2021). Thus, all candidates received the same main questions, ensuring equal treatment and providing a basis for assessment, while the interview is partly shaped by the candidate's responses.

The principles described by Brinkmann and Kvale (2018) were utilized in crafting the interview questions to minimize the influence on interviewees’ thoughts and

responses. Brinkmann and Kvale speak about asking questions that do not affect the interviewees' answer, such as biased questions where the interviewer attains an answer that suits their own hypothesis. This methodology ensured the maintenance of a clear separation between the interview responses and the authors' personal opinions and perspectives.

2.2.2 Foundational Interviews

Foundational or pilot interviews were used as preparation for the main empirical interviews (Majid et al., 2017). These were useful procedures when preparing the full-scale study as they provided a foundational knowledge for the research topic (Tashakkori & Teddlie, 2003). Foundational interviews helped identify practical issues such as prejudice regarding waste generated during the clinical supply chain (Van Teijlingen & Hundley, 2002). The list of interview questions was strengthened by using foundational interviews since it helped identify flaws or limitations within the interview design (Kvale, 2007). The questions used during the foundational interviews were based on understanding if there was an issue with waste within the supply chain, and finding who should have been interviewed to answer the research questions.

At the inception of the study relatively unstructured interviews were performed with a broad selection of AstraZeneca employees, most notably personnel involved in supply chain management and waste management. These interviews were conducted with the aim of collecting data regarding the fundamental aspects of the clinical supply chain. To gather this information, three interviews were held with questions regarding the subject but also finding new interviewees that the person being interviewed recommends.

In late January, interviews were conducted as the project commenced. These interviews lasted approximately an hour each and involved individuals holding prominent roles within the clinical supply chain. They included those pivotal in designing value chains, formulating strategic plans, and overseeing teams responsible for various studies.

2.3 Method for Analysis

During and after the interview process, the analysis and discussion of them began. This was an iterative way of working as discussion began after each interview as the answers were analysed to search for new information that could be used for future interviews. See "*Figure 2*" to see the process of the research and how it was iterative. Throughout the interviews several points consequently re-emerged. These were categorised and grouped depending on the issues they concerned. The salient themes were then mapped on to the processes, to present a mapping of waste and

its sources throughout the supply chain. These were then compiled into specific issues that are later discussed and analysed.

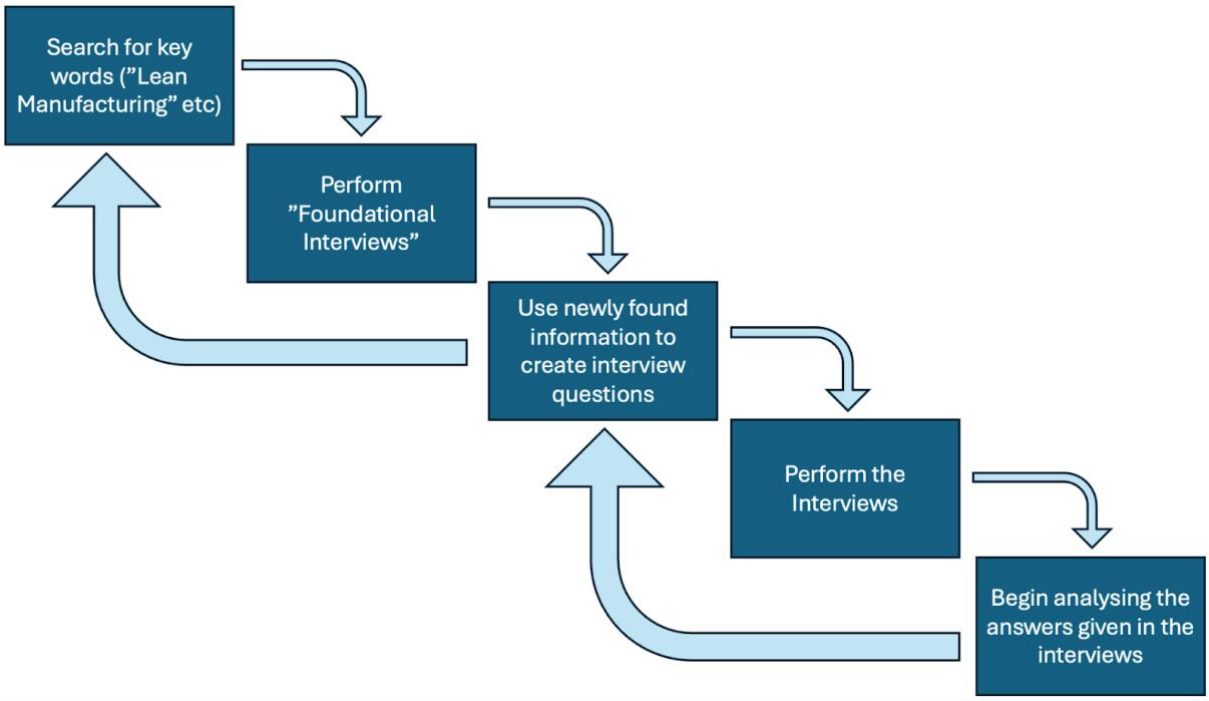

Figure 2: *The research process shown visually.*

The discussion entailed analysing the answers from the interviews and comparing them to each other. Answers were primarily compared to uncover systematic differences while also looking at similarities between interviewees (Ludbrook, 1997). Since the same interview guide was used during each interview, the interviewees had the same opportunity to answer the questions, so different answers were a result of the interviewees experiencing the same issue in different ways. Therefore, this bias is taken into account but is considered important and useful since the study's purpose is to find mechanisms that generate waste.

Lean manufacturing principles were employed to analyse the interview responses. Many of the issues raised during the interviews were seen as addressable through the application of specific lean manufacturing methods. Given that waste reduction is a central focus of lean principles, they were needed for this study's context.

2.4 Quality, Ethics, and Limitations

Bryman and Bell (2015) discuss the four primary considerations that should be looked at when performing interviews regarding ethics. These are potential harm to participants, ensuring informed consent, respecting privacy, and avoiding deception.

Potential harm to participants can be shown in many forms, such as physical harm, stress, damage to self-esteem and more (Bell, 2018). To minimise stress during the interviews, strategies such as allowing the interviewee to take their time to answer

the different questions and providing clear outlines of discussion topics. Participants were also given the option to not participate in the project and decline in answering certain questions.

Before the interviews, the participants were informed about the importance of consent (Bell, 2018). To do this, information about the reason for the interview was given and the participant always had the possibility to question our reasons and how the information given would be used. This helped with the ethical issue regarding information about consent.

Invasion of privacy involves disregarding an individual's right to confidentiality or treating them solely as a data point (Bell, 2018). To safeguard participants' privacy, anonymity was offered throughout the research process. Participants were given the choice to consent to being recorded during interviews, granting them control over their personal information and ensuring their comfort.

Deception occurs when the research misrepresents its true nature (Bell, 2018). To prevent this, the thesis has been quality reviewed and discussed with peers and supervisors. The thesis will also be publicly accessible.

By addressing these ethical considerations, the research endeavours to uphold the rights and well-being of its participants while maintaining the integrity of the study.

2.5 Summary of Method

The methodology chapter of the thesis delineates the methodological framework adopted for investigating waste within AstraZeneca's clinical supply chain. The chapter commences by outlining the integration of a literature review and qualitative interviews aimed at mapping waste production points and identifying inefficiency causes within the clinical trials supply chain.

The segment on the interview study elaborates on the selection of interviewees, the rationale behind using semi-structured interviews, and the execution of these interviews primarily via Microsoft Teams due to geographical dispersion of the interviewees. It stresses the initial foundational interviews, which were pivotal in shaping the subsequent interview questions and fine-tuning the research focus.

The methodology for analysis is described as iterative, facilitating flexibility to incorporate new insights and adjust the research trajectory accordingly. This approach underscores the dynamic interaction between theoretical constructs and empirical data, ensuring that theoretical applications are continuously refined considering new evidence.

Furthermore, the chapter discusses the ethical considerations adhered to during the research, emphasising the protection of participant confidentiality, informed consent, and the ethical handling of the information gathered. The quality, potential biases, and limitations of the methodological approach are critically examined to provide transparency regarding the research's scope and the reliability of the findings.

3. Theoretical Background

This section is concerned with the theoretical framework(s) used to analyse the results from the thesis. The most central theories used will be presented shortly, as well as highlighting any pivotal models, phrases and/or sub-theories from the aforementioned theories.

3.1 Supply Chain

To understand supply chain, one first needs to understand the concept of logistics. Logistics is, first and foremost, a perspective which seeks to monitor, plan, and control the flow of material and/or services, and doing so in the manner most efficient (Jonsson & Mattsson, 2016). Logistics can be studied in one specific organisation, or in a series of organisations, all the way to an end customer. The flow of material or services towards a customer is known as forward flow. It is however important to keep in mind that there also exists a reverse flow, carrying for example returned products back towards the company (Jonsson & Mattsson, 2016).

Supply chain management is often used synonymously to logistics, and while it concerns itself with the same processes, mainly the flow of goods and services, it carries a different perspective according to Jonsson and Mattsson (2016). Supply chain management seeks to emphasise that the organisation is part of a greater network of companies that together create a value chain for the product. These chains of companies that work on a product at different stages together form a supply chain. The central difference to traditional logistics would be a large emphasis on coordinating the organisation's flow of materials with other companies in the supply chain, to maximise flow throughout the whole chain.

3.1.1 Clinical Supply Chain

Supply chain management involves ensuring the smooth movement of goods and services from production to consumption. Clinical supply chain management, on the other hand, is a more specialised form of this process, particularly focused on the intricacies of handling medical products (Abdelkafi et al., 2009). The pharmaceutical industry encompasses the processes, organisations, and operations dedicated to the development, design, and manufacture of beneficial pharmaceutical drugs (Shah, 2004). The intricacies within clinical supply chains involve dealing with factors such as expiration dates of medicines, specific requirements related to medical research, and the complexities of international drug labelling regulations. At the beginning of a trial, forecasting for demand is crucial when creating schedules, procurement, and inventory management (Pang et al., 2023). According to literature, there are challenges within forecasting where predicting the required quantity is difficult (Guibelondo, 2023). This is difficult within the clinical supply chain as demand is

challenging to forecast which in turn generates uncertainties within the other parts of the planning process of a trial.

Notably, the highly variable nature of clinical studies creates an environment where each study is unique, making it difficult to standardise procedural protocols (Abdelkafi et al., 2009). Consequently, predicting the dynamics of the supply chain becomes challenging, given the inherent variability in demand throughout the course of a study. The need to provide the necessary medication to specific patients within set time limits increases the related uncertainties. As Lee discusses (2002), managing supply chains poses a complex and challenging task due to evolving trends such as an expanding variety of products, short product life cycles, increased outsourcing, continuous advancements in information technology, and the globalisation of businesses. Additionally, it involves significant expenditure of both time and cost in conducting clinical trials as it faces challenges like high uncertainties in demand and capacity planning (Lainez, 2012).

To minimise the attendant risks, various strategies are commonly employed within different clinical supply chains, including heightened shipment frequency, overproduction as a precautionary measure, and the implementation of real-time inventory tracking mechanisms (Abdelkafi et al., 2009). However, these approaches are not without drawbacks, such as increased operational costs and an increase in the volume of discarded products. The goal for clinical supply chains to align precisely with demand is central, although it involves higher costs and the challenging task of balancing expenses with risk management in each unique study. Pisano (2000) explores the idea that the pharmaceutical sector can benefit from studying operational excellence practices in other industries. Specifically, Pisano highlights the importance of addressing cost-effectiveness and reducing lead times, which are identified as significant challenges within the pharmaceutical field. Given the focus on reducing lead times and waste, Lean Manufacturing could be an instrument to improve clinical supply chains.

3.2 Lean Manufacturing

Lean manufacturing is a commonly used name for Toyota's production system, also known as TPS, Liker tells us (2020). There are four cornerstones in lean manufacturing, the four P:s as Liker calls them. They are Philosophy, Process, People and Problem Solving. Below each of the four P:s are shortly explained, according to Liker:

> Philosophy: To base decisions in the company's fundamental business philosophy.

Process: To be process oriented, thinking of a company as a set of processes, and continually seeking to improve those same processes.

People: People are the most valuable asset in any company. Lean manufacturing seeks to give its people, most specifically employees although other stakeholders are also included, the tools they need to succeed, such as visual aids and the correct education. It also seeks to take advantage of all the knowledge in the organisation, by involving the employees in creating the work standards themselves.

Problem solving: Viewing problems as opportunities to grow. To opt out of band aid solutions, and get to the root cause, and in the process improving the understanding of the company's processes, and how to improve them further.

By utilising these principles, Toyota seeks to eliminate waste. Liker describes the reduction of waste as the heart of Toyota's business model (2020). What Toyota means by waste is described below briefly.

3.2.1 Waste

In lean management the term "Muda" is often used to talk about waste, being the Japanese word for the same term. The benefits of reducing waste in an organisation are significant, including but not limited to; lower total costs, higher delivery accuracy and higher levels of quality according to Liker and Meier (2006). It's emphasised that eliminating waste in a lean context starts with the first P, Philosophy. This means that it's viewed to be a necessity to start with, or build, a company philosophy with a strong focus on reducing waste to succeed with any long-term waste-reducing efforts. Secondly, it is mentioned that in most organisations a large share of all waste stems from poor processes lacking in consistency resulting in varied results as well as methods of working. Therefore, standardisation is a pivotal tool to be used in the elimination of waste (Liker & Meier, 2006).

Standardisation is used with the aim of making processes more stable and repeatable, effectively reducing variance in both methods of working and results. When a process becomes more standardised and clearly defined, deviations from the norm, also called abnormal or nonstandard methods, become increasingly visible and therefore become easier to identify and adjust working methods (Liker & Meier, 2006).

Below is a flowchart graphically illustrating how work towards waste elimination, specifically by reducing variation is conducted.

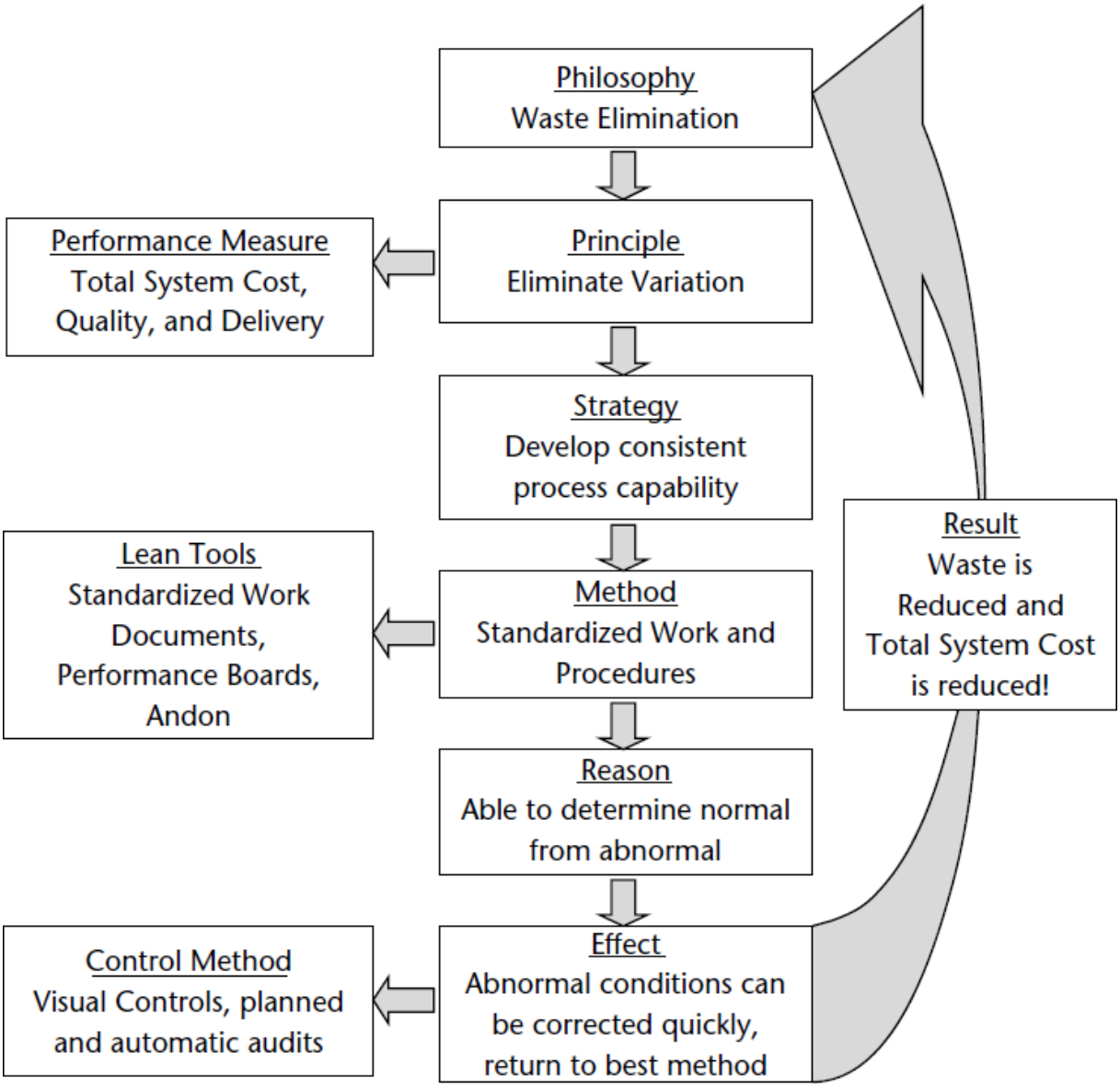

***Figure 3**: Flowchart picturing waste elimination in a Lean perspective. Toyota Way Fieldbook, 1st Edition (Liker & Meier, 2006)*

As is evident from the previous text segments, waste and standardising work are tightly correlated. In the next subheading standardised work in a lean context is explained more in depth.

To understand waste, it is also fundamental to grasp the concept of Value-Added Time. Value-Added Time is the time spent on directly increasing the value of a product or service. For example, in producing a hammer, casting the hammer head would constitute Value-Added Time. All other time, such as storage or transportation, constitute Non-Value-Added Time. A central process in Lean manufacturing is seeking to eliminate as much Non-Value-Added Time as possible, since it constitutes waste (Liker, 2020).

Toyota has categorised seven (7) forms of fundamental waste. These are, according to Liker (2020):

1. *Overproduction*
   To produce more than what is required at any specific time. This is often viewed as the fundamental form of waste since most other forms of waste stems from it. Can generate waste in the form of overstaffing, unnecessary storage, and additional transportation.
2. *Waiting (time on hand)*
   Waiting for a process to complete, this is unproductive time.
3. *Unnecessary transport or conveyance*
   Moving materials or people without proper reason. Can also be inefficient or unnecessarily long moving paths.
4. *Overprocessing or incorrect processing*
   The inclusion of unnecessary steps in a production process is a form of waste. Also to process inefficiently by utilising subpar methods or tools can be included.
5. *Excess inventory*
   To carry more inventory than necessary. This causes waste by leading to longer lead time, and thus increased risk of obsolescence, requiring more transport and increasing storage demands.
6. *Unnecessary movement*
   Movement not directly contributing to production. An example could be retrieving tools or parts, another example could be walking.
7. *Defects*
   The production of faulty products, having to be reworked, scrapped, or replaced.

Waste in this thesis is viewed through the lens of a Clinical Supply Chain. When referring to waste, the specific type of waste intended is the waste of medical products, not time or employee resources. Therefore, some types of waste that Toyota conceptualises will be less studied as they are not directly related to the waste of concrete products, such as time on hand or unnecessary movement.

3.2.2 Standardised Work Procedures

Standardising a task is viewed as a foundational tool in the lean toolbox according to Liker. The process of standardisation is fundamental in guaranteeing quality and enabling continuous improvement (2020).

When the process is stable and standardised, the output is also more stable. By reducing the risk of subpar working methods, the risk of subpar products is similarly reduced.

Liker explains that the reason that standardisation and continuous improvement go hand in hand is that for any improvement to be useful it must stick. Any improvement that comes and goes is just added variance to the process. By standardising you make the process stable, and thus able to integrate improvements into the process, making lasting positive change and not just increasing variance.

3.2.3 Continuous Improvement

In lean philosophy continuous improvement is illustrated through the lens of *Kaizen* as claimed by McCarty, Daniels, Bremer and Gupta, P. (2005). *Kaizen* is simply Japanese for continuous improvement. The central idea is to not view a process as if in a solid state, but rather a dynamic state. There is no perfect process since there is always room to improve. The main forms of improvement sought are normally reductions in waste, speeding up cycle times and better, more stable, flow throughout the process. Any improvements pursued should be linked to the company's strategy, ensuring that improvement translates into desired outcomes. As is apparent from the text the concept of “processes” is central in the concept of continuous improvement, and it can be said to be a rather systems-based approach.

3.3 Sustainability

A well-known definition of sustainable development is postulated by the World Commission on Environment and Development in the report *Our Common Future* and goes as follows: *“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* (1988).

Sustainability is a complex and multifaceted word. It is commonly understood to have three main aspects, according to Hedenus, Persson, and Sprei, (2018). These aspects are ecological sustainability, social sustainability, and economical sustainability. The thesis is primarily concerned with the ecological and economical dimensions of sustainability, but all main axes of sustainability are described below briefly.

3.3.1 Ecological Sustainability

Ecological sustainability is concerned with maintenance of certain systems in nature that provide utility to humanity. These systems are classified as either (i) productive or (ii) absorptive (Hedenus et al., 2018).

Productive systems would be systems in nature that produce things of use. This could include things such as clean drinking water, wood from forests or metals from Earth’s crust. Absorptive systems on the other hand are systems that are able to

absorb emissions or other substances or actions that have effects on nature, like how trees are able to absorb carbon dioxide (Hedenus et al., 2018).

Hedenus et al. further mention that sometimes biodiversity is also included, this is however up for much debate, as biodiversity is only positive when it creates other tangible benefits, and thus is not always included (2018).

3.3.2 Economical Sustainability

Economical sustainability is, perhaps slightly counterintuitively, not mainly concerned with money or expenses, but rather how to use the limited resources available. These resources are classified into two broad groups, finite natural resources (i), and human-created capital (ii) (Hedenus et al., 2018).

Finite natural resources are resources in nature that are useful to humans but are not regenerative (or at least regenerated so slowly that for practical purposes it can be viewed as non-regenerative). Some examples would be coal, oil, and metals in the earth's crust. Human-created capital are things created by humans that facilitate production of useful things, such as infrastructure like roads, or factories. It is not necessarily only physical things, it can also be knowledge or methods, created by scientific discovery (Hedenus et al., 2018).

Economical sustainability, with regards to finite natural resources, would be the process of distributing these resources, both regarding the current population, but also between current and future generations, with the goal to grant the needs of today, with reducing future generations' abilities to do the same. This is challenging both due to the limited nature of these resources, but also because of our lack of knowledge about the future, and what resources they will need (Hedenus et al., 2018).

When viewed through the lens of human-created capital, economical sustainability would be the maintenance and care of what has already been produced, as well as further developing it. Hedenus et al. takes special note of the universities, and their roles in maintenance and development of knowledge, one central type of human-created capital (2018).

3.3.3 Social Sustainability

According to Hedenus, Persson and Sprei social sustainability is primarily concerned with the degree of trust in social relations, both horizontal and vertical. Horizontal social relations are relations between peers, both people and organisations, whereas vertical social relations describe the relations between institutes of power, such as courts and other stately institutions, and its subjects (2018).

3.4 Industry Specific Theory

In this section, terms connected to the pharmaceutical industry that are relevant to the thesis will be further explained. The following terms are relevant to the thesis and have been brought up continually during interviews but are not inherently obvious to a person outside the medical field. Therefore, a brief explanation of each follow.

3.4.1 Shelf-Life

In the European Union, a stipulation mandates that all prescription medications possess a designated shelf life, commonly referred to as an expiration date (Capen et al., 2012). This date must be prominently displayed on the container label, thereby ensuring that consumers are well informed regarding the point at which a medication surpasses its expiration threshold. The International Conference on Harmonisation of Technical Requirements for the Registration of Pharmaceuticals for Human Use offers a formal definition of shelf life as follows: “The time period during which a drug product is expected to remain within the approved shelf-life specification, provided that it is stored under the conditions defined on the container label”.

3.4.1.1 Shelf-Life Extension

The shelf life of a medicinal product is based on stability studies of the product in different environments governed on global standards. For early phase clinical trials, the product development is in its early stages and the stability of the formulated product is typically not fully assessed. As the product development progress and stability studies generate more data, the shelf life of the medicinal product might be extended. Shelf-life extension regards extending the expiration date marked on a product (O’Donnell, 2020). Shelf-life extension is often used when there is low risk to affecting product quality and it enables a longer life for a product. The approach promotes regulatory flexibility, allowing changes to extend the expiry date and therefore minimise waste. The regulatory impact affects if extension of shelf life is possible and varies by country. Therefore, it is difficult to implement at all sites the study is carried out in.

3.4.2 Patient Recruitment for Clinical Trials

During a clinical trial, there is an ongoing recruitment to enrol specific patients to the study. The recruitment process is complex with several assumptions and unknowns (Thoma et al., 2010). The patient recruitment process at AstraZeneca was described during the foundational interviews that it typically starts with a feasibility study to understand the patient population in different markets and to identify several potential candidates. After local regulatory and ethical approvals, the patient screening can start. In the screening phase the identified patients are screened to confirm that they are eligible to participate in the clinical trial based on the set criteria in the clinical study protocol. If eligible, the patient will enter the clinical trial and be dispensed study drugs. This process is long, very unsure, and difficult to predict since the data

regarding the number of possible patients can change quickly. The possibility of changes and difficulties with recruitment is very different depending on the disease and location for the trial. The recruitment will either be referred to as enrolment or recruitment in the thesis.

3.4.3 Forecasting and Expectations Agreement - FEA

During the empirical interviews the interviewees talked about a Forecasting and Expectations Agreement (FEA). FEA refers to a specific document that represents an agreement between the clinical team and the supply chain team. All studies are required to have a FEA since roughly a year and a half back. This document is specific to AstraZeneca. The clinical team is primarily responsible for the planning and execution of the study, and the supply chain teams' responsibility is distribution and manufacturing of the product. The FEA is always tied to a specific study that both teams are working on. Its purpose is to specify several assumptions tied to the study, such as the rate of recruitment of subjects to the study, as well as the total number of participants the study aims to engage. This clarifies the clinical team's intentions for the study and helps the supply chain team gauge the distribution.

There is currently little standardisation in how the FEA is used in different studies, and depending on the teams involved there can be a large amount of variance in what capacity the FEA is used.

3.4.4 Supply Chain Forecasting Program

There are digital tools in place to help supply teams make predictions regarding where and when kits[1] will be needed at certain sites. By feeding the program data such as recruitment size and rate the program can create strategies for supplying specific sites where kits are distributed to subjects, while seeking to minimise waste.

3.4.5 Clinical Labelling

Clinical labelling is a critical step in the Clinical Supply Chain to ensure patient safety, product information and compliance. This process concerns the manufacturing step of medicinal products where the product is labelled for the chosen study. The label gives information such as expiration date, study name and warning text corresponding to the countries in which the drug will be used. The label requirements are regulated by different Regulatory Health Authorities such as Food and Drug Administration (FDA) and European Medicines Agency (EMA).

3.4.5.1 Digital Labelling

Another form of labelling is digital labelling or e-labelling (Matsui et al., 2022). E-labelling is described as a pivotal component of the ongoing digital transformation within the healthcare and pharmaceutical sectors. This innovative approach involves

[1] Kits are packaged containing active drugs or placebo.

the dynamic spreading of updated product labelling through electronic channels, ensuring immediate accessibility to stakeholders such as regulators, industry professionals, healthcare providers (HCPs), and patients.

Digital labelling aims to ensure that the most current information regarding medical products is readily available and comprehensible to all parties involved (Matsui et al., 2022). By facilitating the updated labelling, e-labelling initiatives contribute significantly to the understanding of the medication and ultimately improving patient outcomes since they better understand what the usage of medication will result in. It also offers a possibility for personalised and user-friendly information, where the information is based on the diverse patients such as patients with visual and hearing impairments. Through enhanced features and tailored content, e-labelling endeavours to empower patients with disabilities, ensuring equitable access to vital medical information.

While there may not be a standardised definition of e-labelling on a global scale, its overarching goal remains consistent: to provide comprehensive product information through electronic means (Matsui et al., 2022).

When using digital labels, consumers have a need for risk assessment and technology acceptance that needs to be fulfilled for it to be useful (Tanner et al., 2019). If the consumers have an uncertain attitude toward the new technology, it can create resistance, which can affect the amount of usage of the technology. QR-codes are often used when buying goods, where the code is used to find more information regarding the product, but for it to be the only source of information, it must be accepted by the consumers to be a viable option for labelling.

When implementing digital labels, QR-codes have been discussed as the most useful tool when adding an electronic aid to find more information regarding a product (Violino, S., et al., 2019). By simply scanning, more information can be found regarding the product in either a phone, computer or other tool that has the ability to read code.

3.4.6 Waste in the Clinical Supply Chain

There are currently large amounts of inefficiencies and waste in the clinical supply chain. Upwards of 40 percent of costs in the medical field stem from costs associated with the supply chain. Theoretical estimations suggest that costs associated with the supply chain in the medical field could be as low as two to eight percent (McKone-Sweet et al., 2005). This is further highlighted by Kwon et al. who reports supply chain costs in the clinical supply chain as 38 percent of costs, much higher than fields such as retail with supply chain costs at five percent of costs and the electronic industry with supply chain costs at two percent of costs. As mentioned earlier in the

thesis AstraZeneca's' internal numbers suggest that upwards of 50 percent of all drugs produced are scrapped.

These levels of waste can be problematic, in part due to the resource and environmental costs in producing them unnecessarily, but many types of waste from the clinical supply chain may also be actively harmful. It may be infectious, contain chemicals that affect life and environment, or be hazardous in other ways such as injection needles. Roughly 15 percent of the waste generated by health-care activities is considered to be hazardous in some way (WHO, 2018). Having small amounts of waste could therefore be argued to be even more central in the clinical supply chain as opposed to other fields.

3.5 Summary of Theory

The theoretical background elaborates on the frameworks utilised in analysing logistics and supply chain management, particularly focusing on the pharmaceutical sector. Logistics is defined as the efficient planning, monitoring, and control of material and service flows, crucial in both individual organisations and broader networks extending to end customers. Supply Chain Management, often used interchangeably with logistics, adds a layer of complexity by emphasising the coordination of these flows across different organisations to optimise the entire supply chain's efficiency.

In the realm of clinical supply chain management, unique challenges arise, such as managing the expiration dates of medical products and navigating complex regulatory landscapes. The unpredictability of demand in clinical trials makes planning particularly challenging, necessitating strategies that address these uncertainties while balancing risk and efficiency.

Lean manufacturing, epitomised by Toyota's production system, is predicated on the principles of Philosophy, Process, People, and Problem Solving. This approach aims to eliminate waste, termed 'Muda', and enhance process efficiency through continuous improvement and standardisation. The philosophy extends beyond manufacturing to influence various sectors, including pharmaceuticals, where process optimization and waste reduction are vital.

Sustainability also features prominently in the chapter, with a focus on ecological, economic, and social dimensions. Ecological sustainability involves maintaining natural systems that provide utilities to humans, while economic sustainability is concerned with the judicious use of finite natural resources and human-created capital to meet both current and future needs. Social sustainability emphasises the integrity of social relations.

Specific to the pharmaceutical industry, concepts such as shelf life, clinical trial enrolment, and Forecasting and Expectations Agreement (FEA) are critical. These elements ensure that medications are used within their effective periods and that trials are adequately staffed and supplied. Additionally, the advent of digital labelling represents a significant shift towards using electronic means to provide comprehensive product information, thereby improving accessibility and patient outcomes.

In summary, the theoretical background integrates concepts from supply chain management, lean manufacturing, and sustainability to address the complex demands of the pharmaceutical industry, highlighting the need for standardisation, continuous adaptation, and improvement in practices.

4. Results

This section of the report presents the findings from the empirical interviews conducted with the Supply Leads. The objective is to collate the data and insights shared by the interviewees and systematically emphasise recurring themes. The presented results consist of responses provided during the interviews.

4.1 Reasons for Discarding of Products

The interviewees were largely in agreement over what the main reasons for scrapping of product was. This chapter seeks to summarise and clearly state the salient issues.

4.1.1 Forecasting

The early stage of the process is characterised by a large amount of uncertainty, and that also reflects on the main factors leading to scrapping at this stage. It was clear from the interviews that a big challenge was forecasting the patient recruitment, both the total number and their geographical distribution. By having too much product at certain sites the risk of product expiration was substantially increased due to difficulties of redistribution.

Currently there are tools available to employees that aim to alleviate uncertainties in supplying sites. These tools are mainly digital programs using advanced statistical methods that forecast supplying needs. These tools hinge on receiving correct and up to date information, as any prediction can only be as good as the data it is based on. The consensus was that there were large variations in how effectively these tools were used. Most interviewees felt that the tools were not used to their full capacity for two main reasons. First, the work was unsystematic, the interviewees felt that they were not positive with what information to feed the program and how often to update it. Some of the interviewees reported that there were large variations in how the work was performed, and it was largely up to individual study leads how the work was carried out for each study. The second issue brought up was a lack of knowledge regarding the system. The interviewees pointed out how the main system used are very complex, and most felt that many lacked the prerequisite knowledge to fully utilise it, ”*People are not very flexible and do not understand the system very well, so they only work with the planning between certain decided dates, when you actually should update the system much more often to get even better numbers*” as declared by one interviewee. When asked whether work with the program is standardised in a follow up question an interviewee claimed “*No it is not, you are driven by yourself, you can do the bare minimum. There are big differences depending on who uses the progra*m”. Some mentioned that guides, courses, or other types of educational material could potentially be helpful, or as one interviewee put it, “*It is a complicated program, there has to be better guidance in how you should use it*”.

4.1.2 Labelling

Another clear source of waste was the labelling process. Since it is a highly complex process it is not uncommon to have to scrap batches due to errors made in the labelling process, with an interviewee claiming that "*Labelling is a huge reason for creation of waste*". An example given of a quality issue that could occur during the labelling process was "*Labels not sticking to the bottle and therefore not going through the quality control*". Labelling the product also indirectly increased waste by making recycling and/or reuse in a different study almost impossible, since the labelling process is unique to each study, large and complex rework would be required. According to the interviewees the process is so cumbersome that reworking product is very rarely justified, and thus scrapping and new production was the regular approach. To give an example an interviewee claimed, when asked about the views on recycling products "*The normal question is why would you reuse it, not why aren't we doing it?*".

4.1.3 Changes in Study Design

A source of waste that was most significant predominantly in the early stages was changes in study design. To give an example, a subgroup of patients could be dropped from the study, leading to the kits associated with that subgroup to be almost entirely useless, usually resulting in large amounts of kits being scrapped. This happened to one interviewee, who described that "*Recruitment was stopped and then amended, two arms were dropped, placebo and another, and a new arm was added*" when asked for the main reason for the creation of waste in a specific study.

4.1.4 Drug Expiration

Drug expiring and being scrapped was a continual source of waste. Drugs usually have a very limited shelf life early in the process, but as the compound is made more stable and subjected to further tests extending shelf life is a possibility. This is however often not exploited since the procedure is very difficult once the product has been labelled. The problem was further exacerbated by long lead times. Lead time tends to be very long, both due to the nature of the business, being very complex, but also due to preventable reasons such as procuring product in very large batches and inefficiencies in the supply chain. "*When we went from procuring batches every four months to every two months, we saw a drastic reduction in product expiry*" one interviewee told, speaking on the merits of reducing lead time by reducing batch size and its effects on waste. There were measures mentioned aimed at reducing lead time by altering supply strategy, such as moving production closer to where the product will be used.

4.1.5 Regulatory Challenges

The interviewees also mentioned regulatory reasons as contributing to waste. The specific countries have been redacted as it could be considered politically sensitive information. For example, sites in certain countries have regulations requiring the product being a certain amount of time from expiry for them to accept the drug, "*[REDACTED] only accepts products of a certain shelf life*" as exemplified by an interviewee. Another mentioned how "*some sites refuse to use the drug when there is less than six or three months left on the shelf life. This issue is mainly [REDACTED], you pack them in specific ways which means that the drugs cannot be used in other countries*". This effectively shortened usable shelf life and increased risk of expiry. Clinical sites regulating the size of batches was another reason mentioned adding complexity to the supply chain and possibly adding waste by increasing risk of expiry, for example "*Local random restrictions such as in [REDACTED] markets*" one interviewee stated when asked about sources of waste.

4.1.6 Team Communication

Another challenge that was brought up by the interviewees was communication between teams. The interviewees agreed that it was very different from study to study, it was said that "*Communication between teams is very study specific*" by an interviewee. Another interviewee similarly stated, "*The communication is varied between studies, the better the communication, the better choices can be made early in the study and not make big changes too late in the project*". Most claimed to be aware of studies where communication between different involved teams was a significant hurdle. An interviewee told of how "*When temperature excursion was not communicated so the bottles were still in stock which took unnecessary space and time*" when asked to give an example of poor communication. The main pathway through which communication, or lack thereof, contributed to waste was by restricting access to data, feeding into the challenges in forecasting needs. When asked why communication sometimes lacked, the responses were similar; due to the flexible and dynamic nature of the business, teams generally "*Do not like to commit*" as one interviewee said, which can be problematic since until quantities are committed, planning for supplying the same quantities cannot be done, at least not fully.

4.1.7 Other Issues

This section will go over some of the issues that were not brought up quite enough to merit a subheading yet were brought up to an extent where not mentioning them would be amiss.

Four out of six interviewees mentioned the issue of product perishing due to temperature fluctuations during the chain of transportation. None extrapolated much

on this statement however as this was agreed to be responsible for relatively minor amounts of waste.

Unforeseen events, specifically the spread of COVID-19 was mentioned, could contribute to increases in waste. "*When the study was designed, many of these studies did not plan on this possibility, where the IMP*[2]*s and the labels had to be suited for the purpose that outsiders can medicate themselves*" one interviewee stated, when describing why COVID-19 led to an increase in waste in a specific study. Many kits had to be reworked which in turn created waste. This issue was mentioned by only one interviewee and might therefore not be generally applicable.

4.2 Occurrence of Waste in Clinical Supply Chain

Most of the interviewees mentioned the beginning and end of studies as significant waste occurrences for some studies. One interviewee said that there was "*Not much waste in the middle, more in the beginning and end*", another describing how there are "*Huge amounts of waste at the study closure when looking at study reports*" and finally one claimed that "*The part where waste is the highest is in the beginning when it is a lot of uncertainty*". Clearly the interviewees had different experiences depending on the study and observed waste at various stages, some putting greater emphasis on early stages and some on study closure, with no one opposing the middle stages being a generally low waste period.

The interviewees agreed that the reason for this is because a lot of discarding is done in the beginning. Consequently, the forecasting is still unsure and not specific which results in manufacturing more than what was needed. The end of a study is significant since this is when the study is closed, and all the product and material left will most likely not be reused and therefore discarded. At this point, the discarding is primarily identified because of products being inventoried and an exact number called "End of study waste" is counted and all waste is accumulated.

Discarding of products is an ongoing process since products expire at different stages and inventory is kept during the entire process so that it is known when products should be discarded. In the early stages, some of the waste is created due to labelling errors, while waste during the middle of the study can be because of temperature excursions and deviations during manufacturing. Most interviewees mentioned that the waste during the middle of the study is not significant since the enrolment of patients is finished, and the demand is known. Therefore, manufacturing can produce more exact numbers of products and minimise waste.

[2] IMP stands for investigational medicinal product.

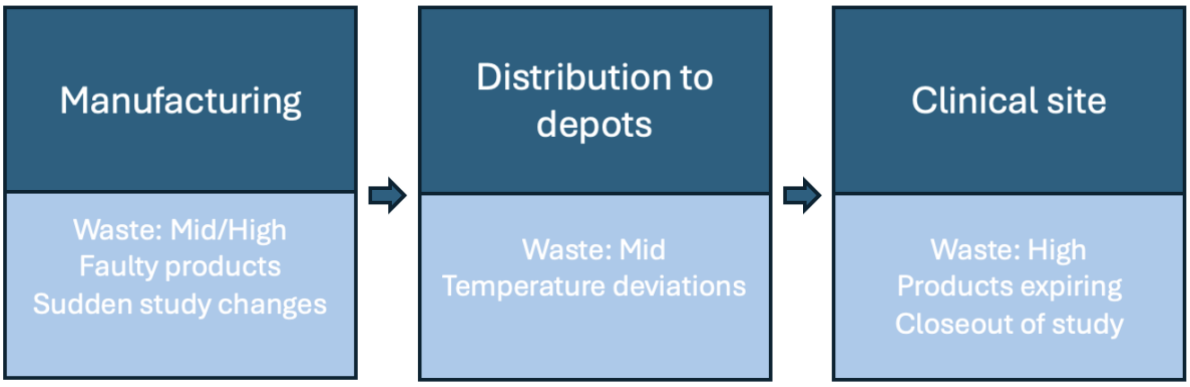

***Figure 4**: Map of where waste is generated during the supply chain, if it is considered high/mid/low, and what the reason for this occurrence is.*

4.3 Management of Discarded Products

When discarding material, there are certain procedures that the product goes through. First, expired stock is typically labelled for destruction, with limited opportunities for reuse or recycling. Relabelling and reuse are hindered by quality assurance requirements and logistical complexities which are not profitable and are not time or cost efficient. Despite efforts, the consensus was that recycling and reuse was very limited. The interviewees discussed the possibility of extending the shelf life and repurposing for other trials, but this is associated with many challenges, which will be further discussed in the analysis.

For recycling initiatives to be possible the conclusion was that the process of reuse would have to be much simplified. Changing specifications, specifically labelling, are currently complex and time intensive, meaning that in most cases it is very economically inefficient to reuse instead of producing new products. Any recycling initiative would need to make the process much simpler and cheaper for it to have a chance at success. An interviewee explicitly stated "*Once it is labelled you cannot reuse it and is therefore discarded*" showing how central the connection between labelling and recycling is.

The interviewees agreed that updating specifications was the main hurdle in reuse, recycling and shelf-life extensions efforts, and making that process simpler was essential in enabling those types of efforts. One interviewee gave an example of an aspect having to be considered when updating specifications, "*Is the label easy to remove? Or do you need solvents to remove them? Some solvents might affect the product*" highlighting the interplay between different chemicals which must be taken into consideration.

Generally, there was a larger emphasis placed on sustainability and possible recycling initiatives from study leads in certain fields.

4.4 Measures to Reduce Waste

There were solutions to reducing waste that were discussed during the interviews. Firstly, these were regarding utilisation of tools for forecasting, scenario planning and waste tracking. Tools such as forecasting supply chain can assist in this since they simulate possible outcomes regarding enrolment, waste, and cost. By having a clearer forecast, waste connected with this could be minimised. "*The study just wasn't recruiting fast enough*" as one of the interviewees put it, explaining why they had oversupplied a study, leading to drug expiry. The recruitment rate simply could not match the forecasted recruitment. Similarly put by a different interviewee "*Recruitment did not give as many patients as needed, but products had already been manufactured*" explaining how poor forecasting of patient recruitment effectively locks Study leads into large reserves of product with accompanying large risks of expiry.

Other measures discussed were the desire for improved communication, flexibility, and integration between clinical and supply chain teams. This can help with creating a better forecast since the difficulties with the study have been communicated between the teams. Communication is not uniform across different studies now and interviewees mention how the FEA can create a better platform for communication, if used correctly and consistently updated with new data and information.

Secondly, another possible solution brought up by interviewees would be the implementation of digital labelling which enables the reuse of products since the information regarding the material can be digitally changed and adjusted to the new study. Anytime updated information was needed such as an unforeseen event or a shelf-life extension a digital label that could be easily updated could prevent a large amount of scrapping. One of the interviewees mentioned with regards to digital labelling "*Hopefully we'd see something like that in our lifetimes, I think that could reduce a lot of waste*". Challenges were also brought up however, mainly conforming to regulations, ease of use and different levels of digital infrastructure being available in different countries.

To further improve the reduction of waste, there should be measures regarding traceability and standardised documentation. This will help with being able to go back and look at previous studies to learn and understand how future studies can be improved.

4.5 Summary of Results

The results chapter presents a retelling of the findings from the empirical interview on the waste situation within AstraZeneca's clinical supply chain, focusing on the factors contributing to waste and strategies for its reduction. The chapter highlights several primary sources of waste identified through interviews with supply chain professionals. Foremost among these is the challenge of forecasting, where

inaccuracies in predicting patient recruitment and drug distribution often lead to significant product overstock and eventual waste. Compounding this issue are errors in the labelling process, which not only cause immediate waste when errors occur but also limit the potential for recycling, reuse, and shelf-life extension.

Additionally, changes in study design sometimes necessitated the scrapping of large amounts of existing supplies, as modified study parameters can render previously produced materials obsolete. Drug expiration further contributes to waste, exacerbated by inefficiencies and long lead times within the supply chain that prevent timely utilisation of the drugs. Regulatory challenges also play a role, with local regulations often leading to the discarding of products that fail to meet specific regional criteria.

The management of discarded products is typically constrained by regulatory and logistical challenges, limiting opportunities for recycling and repurposing. Most expired or obsolete products are labelled for destruction, reflecting the quality and safety requirements that govern clinical supplies.

To address these issues, the chapter notes several suggested measures to reduce waste, including improving forecasting accuracy, enhancing communication and integration between clinical and supply chain teams, and implementing digital labelling technologies. These technologies could allow for more flexible and timely updates to product information, reducing the need to discard products due to outdated or incorrect labelling. Overall, the chapter underscores the need for strategic interventions to improve efficiency and sustainability in the clinical supply chain at AstraZeneca.

5. Discussion

This chapter seeks to contrast and compare the findings of the study to the theoretical frameworks used, mainly Lean waste-theory, and sustainability. Any similarities, differences, and the underlying reasons for the same will be presented and analysed. Refer to the chapter on theoretical background for information on the foundational frameworks.

5.1 Theoretical discussion

Waste, as the term has been used in this thesis, mostly refers to the scraping, or wastage, of medical products. In the following text, since both the thesis's use of waste, and Lean manufacturing's waste concept is present, waste of medical products will instead be referred to as wastage. This is to reduce any confusion due to the similarities of the terms. Below follows a section exploring how wastage may or may not be like the more generalised concept of waste in Lean Manufacturing, studying which of the seven forms of waste conceived by Toyota are most relevant, and which issues they relate to. For explanations of each form of waste, refer to the theoretical background.

Forecasting the demand for medical products was clearly challenging, and a large culprit in wastage accumulation. The importance and difficulties of forecasting in a clinical supply chain closely reflects the findings in the literature study, from authors such as Guibelondo (2023), Pang et al. (2023) and Lee (2002). The direct form of waste that this most clearly ties in to is over or incorrect processing, although this comes with a few caveats. Since the process must be completed before patient recruitment begins, one could argue that it is inefficient by design. It still holds true however that at least from a waste perspective, this is an inefficient process. The large degree of uncertainty clearly biased the interviewees towards overproduction, the fundamental source of waste in Toyotas framework. This is understandable granted the problems that a missed delivery poses in a research context, however that doesn't take away from the downstream waste this generates in the supply chain. The main method by which this leads to wastage would be that overproduction of drugs leads to excess inventories at clinical sites. This in turn increases the risk of wastage by two main methods. First, by having more inventory, lead times are effectively extended. Assuming demand is constant, a larger inventory takes longer to go through, increasing time spent waiting in storage. The longer lead times are, the larger the risk of product expiring, which the interviews made clear, is a significant reason causing wastage. The second mechanism by which overproduction and in turn excess inventory causes wastage is in the event of changes to a study while it is ongoing, such as changing the geographical distribution. The more product being at sites, the larger the challenge of moving it within the expiry window. Making study changes more complex and difficult is therefore another way in which excess inventory may contribute to increased wastage.

Currently there are limited efforts towards recycling or reusing products. Even when for example a study was shut down and there still were drugs with remaining shelf life available, consensus was that reusing them in a different, similar study was the exception, not the norm. This was purportedly mainly, but not exclusively, due to the difficulty in reworking the product, the relabelling process being the chief issue. Similarly, the difficulties in updating specifications made shelf-life extensions less used than possible, causing products to expire unnecessarily. This could be viewed as over or incorrect processing, assuming there was a better alternative available.

Another form of waste clearly present in the labelling process was defects. As the interviewees mentioned, the process is highly complex, and due to that complexity, it also tended to be the biggest single contributor to creating defective products during the study supply chain.

Currently the relabelling process is complex and cumbersome, and furthermore rarely seen as a viable alternative. One interviewee proclaimed that "*Relabelling is not possible because the majority of the time you need approval from the Quality Assurance team and questions will be asked such as why do you not just produce new products*".

Furthermore, labelling is a clear example of the complex interplay of the different aspects of sustainability. Preventing reuse, recycling and shelf-life extensions was primarily the cost of reworking products. To tie that into sustainability perspectives, the lack of economical sustainability in these processes prevented them from being implemented, despite the benefits to environmental sustainability achieved by scrapping fewer products. This is illustrative of why many scholars use the three-part division of sustainability, environmental, economic and social, and why it is vital to see sustainability as a complete system, where needs from all aspects have to be met. Any intervention seeking to improve the environmental sustainability of this process would be remiss to not also take the economical sustainability of that same process into account.

Similar mechanisms can be seen at work when comparing Oncological[3] and Biopharmaceutical[4] studies. As a broad generalisation, drugs in oncological studies tend to be more expensive than in comparable Biopharmaceutical studies (Serra-Burriel et al., 2023). This was reflected in the interview study, where the Oncological study leads seemed to a larger extent have integrated waste conscious thinking in their daily work. This finding further strengthens the connection between environmental and economical sustainability, albeit in the reverse direction. These findings emphasise that when there is economical sustainability in being more waste

[3] The study and treatment of cancers
[4] Any drug wholly or partly being biological in nature, as opposed to fully synthesised drugs.

conscious, it may promote acting more in accordance with environmentally sustainable paths.

A similar argument could be made regarding overproduction. To reduce the wastage generated due to overproduction and improving sustainability, one would also need to take the economical aspect into account. Currently, most employees reason like this interviewee explained, "*You get flexibility from packing more drugs, but you are not as efficient. The more efficient you are, the higher the risk of not being able to meet the quality needs*". If for example predictions could be improved overproduction could be lessened without harming the financial status or accuracy demands of the company, and ultimately improving environmental sustainability by looking after economical sustainability.

The last aspect of sustainability is social sustainability. The initial foundational interviews did not suggest that social sustainability would be central to the thesis, but its relevance was highlighted once the empirical interviews commenced. When speaking about the FEA it was clear that there were instances when lack of communication between teams was a contributor to wastage. The interviewees concurred that there are large differences between different studies, some with frequent and open communication, and other less so. Sometimes reluctance to share information early reduces the time frame to prepare for study design changes, causing more wastage than necessary. Looking at this from a sustainability point of view, it could be viewed as a breakdown of social sustainability, more specifically a deficit of trust in relations. There seem to be instances of people delaying sharing data until necessary. The main reason for this seems to be a fear of being held too rigidly to uncertain predictions, which is understandable. This however creates difficulties where teams are less prepared than they could be due to not receiving data early. By improving trust in relationships both horizontal, between teams, and vertical, between teams and management, more sharing could be facilitated, if people felt secure in that their predictions would be treated as what they are, best guesses, and not held against them. By improving this social sustainability less wastage could occur, in turn improving both economic and environmental sustainability, once again showcasing the interconnectedness of the different aspects of sustainability, and how important it is to have a cohesive sustainability strategy, taking all aspects into account.

5.2 Summary of Discussion

The discussion chapter engages in a critical discussion, comparing the empirical findings of the study with established theoretical frameworks, particularly focusing on Lean waste-theory and sustainability concepts. This chapter explores how the observed wastage in AstraZeneca's clinical supply chain aligns or diverges from the broader, generalised concept of waste as defined in Lean Manufacturing.

The discussion opens with a theoretical examination, noting that waste in the context of the thesis primarily pertains to the scrapping or disposal of medical products. It contrasts this with the seven forms of waste identified by Toyota. The chapter emphasises that while some forms like overprocessing and excess inventory directly correlate with issues identified in the clinical supply chain, others like waiting and unnecessary movements are less applicable.

A significant part of the chapter is devoted to the challenges of forecasting demand for medical products. It notes that forecasting inaccuracies lead to overproduction, a key source of waste. The difficulties of forecasting in a clinical setting reflect similar findings in the literature, underscoring the complexity and uncertainty inherent in predicting clinical trial requirements. This misalignment often results in excessive inventory, which heightens the risk of product expiration and contributes to increased wastage.

Another major focus is the labelling process, which is pinpointed as a critical area where waste is generated. Errors during labelling not only result in immediate waste due to the need to discard defective batches but also create barriers to recycling and reusing materials. The stringent and specific requirements for each study's labelling make it challenging to repurpose materials for other uses, furthering waste issues.

Moreover, the chapter critiques current recycling and reuse practices within the supply chain. It points out that despite the potential for reusing products with remaining shelf life, such practices are not common, mainly due to economic and regulatory constraints. This leads to a broader discussion on sustainability, suggesting that enhancing waste management practices could not only reduce environmental impact but also improve economic efficiency.

Finally, the discussion suggests that improving communication and data sharing across teams could significantly reduce waste. By fostering better integration and coordination, it is possible to align production more closely with actual needs, thus minimising the risk of overproduction and subsequent waste.

6. Suggested interventions

The aim of this chapter is to present a set of possible solutions to handle the waste problem in the clinical supply chain. It is based on both direct suggestions from the interviewees, as well as the opinions of the authors, based on the findings of study.

6.1 Digital Labelling

Digital labelling is spoken of as one of the most efficient solutions to the problems described during the interviews. Currently there is a large amount of consensus regarding the challenges of sustainable labelling. As mentioned in the result, there are several problems with the impossibility to reuse or recycle the material used in a study. One component of this problem is the difficulties with relabelling since it is not a profitable way of working. Relabelling and reusing products is both time and cost consuming, which is not an efficient way of working since it would result in much more resources needed to complete this work. To facilitate this and enable the reusing of products, the solution with digital labelling will be discussed.

Digital labelling would result in a more efficient way of changing the information for a product. This information could be expiration date, shelf life and name of study. One issue that has been mentioned is the issue with extending the expiry date for a product. With a digital label, the information could easily be updated by changing it in a specific database that updates the information given on the product.

An example on how the information can be found is by using QR-codes or some kind of code that can be scanned through a smartphone or computer. There should also be a serial number or specific code that can be used to search for the information via computer since some do not have access to a smartphone or computer with scanning properties. By scanning or searching for this product, a site will be shown where all data that normally sits on the front of the package is shown. The information can then easily be changed if needed and the patient can always be updated with new expiration dates and so on.

Using digital labelling aids in minimising waste because multiple studies involving the same product often run concurrently or within the same time frame. Therefore, it would be feasible to update the product information based on the requirements of another study. This way, unused products can be easily repurposed.

Using digital labelling could address several issues identified during the interviews. One such issue discussed was the challenge of maintaining quality control when reusing a product. Digital labels offer a solution by simplifying quality control

processes during both manufacturing and throughout the product's lifecycle. This is achieved through quick access to product data via scanned codes. During manufacturing, digital labels reduce the occurrence of faulty labels and the need for rework, as there are fewer risks of errors in labelling. Furthermore, the creation of labels becomes simpler, as much of the information typically found on physical labels can be embedded digitally. In terms of quality control for the physical product, digital labelling smoothens the process, as the primary concern shifts to ensuring the code functions properly and displays the correct information on-screen.

Another issue that digital labelling solves is the inclusion of patients with visual impairments. With a digital label, there will be a possibility to create a function where the information can be read by the computer so the patient with difficulty reading can get the information read to them. This also shortens the manufacturing time since the need for blind text will not be needed to the same extent.

While digital labelling offers numerous advantages, it also presents potential challenges that merit discussion. Most prominent among these is the issue of access to smartphones or digital tools necessary for scanning or searching for specific products. Access levels vary greatly worldwide, complicating universal implementation. Since studies are conducted across diverse regions, ensuring equitable access to digital tools for all stakeholders becomes difficult. This variability in access levels poses a not insignificant barrier to the widespread adoption of digital labelling.

To address this challenge, a targeted approach could be adopted, leveraging digital labelling in regions where most of the population has access to digital tools. By manufacturing products with either traditional labels or digital counterparts, it becomes possible to cater to diverse access levels. Some products could feature traditional labels, providing all necessary information, while others could utilise digital labels. This approach minimises waste since it enables at least some products to be reused. Another way of addressing this challenge is to have computers available at the depot where the kits are given to patients. Thereby, they have some accessibility to digital tools. On the other hand, this might create issues regarding the patient forgetting the information when leaving the clinical site and thereby not having it at hand when needed.

One of the issues that is attacked by using digital labels is environmental sustainability. When minimising the discarding of products caused by defects regarding the label, the environmental impact becomes lower. The reason why rework or the reusing of products is not a solution that is currently being used is because it is not economically viable, which has previously been mentioned. Therefore, economic sustainability becomes a higher priority within the clinical supply chain since high quality is necessary when conducting a study. The products used need to be of the right quality and amount, and at the right place at the right time,

which is often costly since you overproduce to make sure that these criteria are fulfilled. Doing rework on a product is often not profitable and might even affect the quality of the product and study. This issue could possibly be solved by using digital labels. As mentioned, digital labels give manufacturing a possibility to change the information given on the product without having to do manual rework on each product. This will likely have a positive impact on the environmental impact while ensuring the stability of the economic sustainability since this will not be affected to the same extent as manual rework on traditional labels would.

One essential piece of information that labels should provide is the shelf life of a product. However, a common issue arises when the shelf life is extended, requiring manual changes to each label to reflect the updated information. This process not only increases the risk of errors but also poses a potential threat to the product's integrity. By implementing digital labelling, the need for manual label changes is eliminated. Instead, information updates are seamlessly managed through a database that enables continuous changes that might be needed. This ensures that the shelf-life information is always accurate and up-to-date across all products, without the risk of human error or compromising the quality of the product.

As previously discussed, digital labelling reduces the need for manual rework by eliminating the necessity to replace physical labels. This directly addresses another form of waste identified in lean production: overprocessing. Overprocessing is not only costly but also time-consuming. Therefore, the adoption of digital labels offers significant advantages in this regard. By utilising a single digital label and eliminating the need for rework, overprocessing is minimised. This reduction in unnecessary processing streamlines operations, saving both time and resources. Consequently, digital labelling contributes to the overall efficiency of production processes by minimising waste.

In essence, while digital labelling holds promise for enhancing efficiency and accessibility, careful consideration must be given to the challenges surrounding equitable access to digital tools. By implementing a nuanced approach that accounts for regional differences in access levels, it becomes possible to harness the benefits of digital labelling while minimising potential drawbacks.

6.2 FEA as a Communications Tool

As mentioned, the current policy is to have an agreement regarding forecasting and expectations in place for every study, referred to in the study as FEA. This document contains several foundational agreements between a clinical team and a supply team associated with a specific study. Presently there are however large discrepancies in how as well as to what extent the FEA is used in different clinical trials.

To combat this, efforts to improve standardisation of how the FEA is used is suggested. There are currently guidelines on how the FEA should be used, but adherence to these standards seems to be lacking as of the present moment. By increasing standardisation, the supply teams would have a higher likelihood of receiving relevant data. The confusion in how the FEA should be used would be reduced, and by having a more standardised work procedure with, the FEA would be a foundational tool to facilitate continuous improvement of the process. As mentioned in the theory, standardisation is the basis for which continuous improvement is possible, as any improvements will be only temporary unless they are integrated into a standardised workflow.

For standardisation to be effective, there must be enough buy-in from the employees that they want to follow, as well as contribute to the improvement of the standards. As there currently exists standardised ways of working that are not fully utilised, this seems central in the improvement of the FEA. There was a perception that in general, clinical teams did not feel the same level of ownership of the FEA as supply chain teams. This is understandable as the FEA primarily is a tool to help supply chain teams to plan. A suggestion to improve the participation and experienced ownership of the FEA could be introducing a Key Performance Indicator (KPI) that represents some aspect of quality in the work with the FEA. An example KPI could be how closely the assumptions were followed, measuring accuracy, or how often the FEA was updated, measuring communication and cooperation.

A more thoroughly used FEA could reduce waste by providing the supply chain team with high quality up to date information, decreasing the risk of improper allocation which in turn would lower the risk of product expiring. In the case of sudden big changes, such as dropping an arm of a study, a well working FEA facilitating communication could ensure that no more product then absolutely necessarily goes to waste, by continually providing the most up to date information, help the supply chain team make the necessary preparations.

This approach is not without its challenges. The drug business is dynamic, highly technical and complex. A large contributing factor to why there sometimes were reluctance to share data between teams was a fear of being held too tightly to your predictions in such a dynamic field according to the interviewees. Special care would need to be taken that the agreement and/or the KPI promotes sharing data, and not punish it. A risk with a KPI measuring accuracy of the assumptions could risk rewarding withholding data for as long as possible to maximise accuracy and thus actually promoting lower communication and less data sharing. A KPI measuring frequency of updates to the FEA could therefore be a more appropriate measure to properly incentivise sharing data, and not punishing it.

6.3 Advancing the Use of Digital Forecasting Tools

Currently, supply chain teams utilise specialised forecasting tools capable of projecting various parameters such as waste and costs based on input data. These tools enable the simulation of different scenarios to anticipate outcomes according to desired or required information. However, the accuracy of these forecasts depends on the correctness of the input data; inaccurate data can lead to unrealistic simulations. As proclaimed by one interviewee "*Like a cone, there is more uncertainty in the beginning and when more information is given then the uncertainty is minimised since you can forecast better*", highlights the difficulties with the subject matter, as well as the need of good predictions early.

The usage of these predictive tools is very different depending on who is in charge of updating it with new and improved data. Some use it continuously and update information daily or weekly with detailed information, while others use it more rarely, which shows that there is no standardised way to work with these tools. Therefore, further advancement in digital tools can contribute to waste reduction by improving the accuracy of forecasts regarding the required quantity of products during a study.

In the realm of digital forecasting tools, a critical challenge lies in establishing standardised procedures. Drawing from principles of lean production, standardised work emerges as a key strategy for minimising waste along the value chain. By fostering stable and efficient processes, standardised work optimises product output and ensures profitability. Leveraging digital forecasting tools can facilitate the establishment of standardised protocols, as these tools are designed to be utilised consistently across different studies. This entails prescribing a set of required data points for study design, including estimated patient numbers, geographic location, and other necessary information essential for optimal study execution. Enforcing such requirements for every study ensures the tool's utilisation in the most effective manner possible.

Standardised work holds significant importance because it enhances the visibility of deviations occurring during a process. These deviations may not necessarily be specific to a particular study but could be indicative of common problem sources recurring across different studies. The greater the standardisation of a process, the more readily apparent any deviations become. Standardised work also serves as a foundation for continuous improvements, which are necessary since it gives a possibility to be innovative and continuously improve processes. Continuous improvement is essential when working with digital forecasting tools for several reasons. One reason is the adaptability to change. Digital forecasting tools operate in dynamic environments where market conditions, consumer behaviour, and other variables can change rapidly. Continuous improvement ensures that the forecasting models and algorithms can adapt to these changes effectively, providing accurate predictions even in fluctuating conditions. For the clinical supply chain, this means

that a study can quickly change, and the digital forecasting tool can help solve the issues that come to light.

Another reason for working with continuous improvements is the enhanced accuracy. Through continuous improvement, digital forecasting tools can refine their algorithms based on historical data and real-time feedback. This iterative process helps improve the accuracy of forecasts over time, leading to more reliable insights for decision-making. Enhanced accuracy can help the design process of a study since it enables better forecasting regarding how much material that will be needed and at where it should be located. This then helps with avoiding overproduction, which is a form of waste mentioned in lean production. Overproduction is a result of bad planning and unreliable forecasts of the demand, which can be improved by using digital forecasting tools that are continuously improved and updated with correct data.

Continuous improvements also help with optimised performance which means that regular updates and enhancements to digital forecasting tools can lead to improved performance in terms of speed, efficiency, and resource utilisation. This optimisation ensures that the tools can handle large datasets and complex computations efficiently, enabling faster and more robust forecasting processes. This can then help to minimise waste since resource utilisation will be improved. It also improves innovation and creativity within teams. Continuous improvement fosters a culture of innovation and creativity within the team working with the digital forecasting tools. By constantly seeking ways to enhance the tool's capabilities, teams can uncover new approaches, techniques, and features that drive improvements in forecasting accuracy and efficiency.

Lastly, continuous improvements and digital forecasting tools help with cost savings. Improving the accuracy and efficiency of digital forecasting tools can result in cost savings for organisations. By reducing errors, minimising waste, and optimising resource allocation, organisations can achieve better financial outcomes and improve their bottom line. This improves economical sustainability since continuous improvements help with, for instance, reducing costs, enhancing productivity, being innovative and creating value, while also creating long-term stability. It reduces costs since it focuses on identifying and eliminating waste, such as unnecessary expenses in process. As productivity is enhanced with continuous improvements, workflows can become smoother, and the forecasting system becomes more efficient to produce the information needed.

Additionally, digital forecasting tools offer valuable assistance in planning the transportation of products. When accurate data is utilised, these tools can mitigate issues such as excessive product inventory at depots where demand may be lower. Through effective planning and precise forecasting, challenges related to expiry due to improper distribution may be alleviated which can thereby minimise waste within these processes.

The effectiveness of digital tools relies heavily on the accuracy and relevance of the data used when forecasting potential scenarios. Regardless of how advanced or efficient a system may be, it is not useful if inaccurate or irrelevant data is employed. To make use of the full potential of digital tools, it is vital to ensure that the data provided by teams is both correct and useful. Further, standardising the utilisation of these tools across all studies is crucial. This standardisation ensures that each study employs a consistent methodology, enabling all teams to generate the most accurate forecasts possible and thereby minimising waste generation.

6.4 Investigate Lead Time

One thing that was clear from the interviews was that product expiring for different reasons was fundamental in products being scrapped. There are many ways to tackle this issue already mentioned such as promoting shelf-life extensions through digital labelling, improving supplying strategy with more effective use of forecasting tools and so on, but a simple strategy to effectively extend shelf life and decreasing the risk of product obsolescence would be to reduce lead time in the supply chain. This might however not be as simple as it sounds. As one interviewee mentioned, "*The product is usually acquired in large batches, so just reducing lead time in the distribution might not reduce expirations*", so to yield effective results, the efforts would have to be combined with a revised buying strategy. This would be a major change, but as expiration of products is such a major issue it at least merits an investigation.

As this study has been overarching in its aim and sought to look at the process, there are no precise suggestions how to reduce lead time operationally. The conclusions are simply that it is an issue and further, more specific, investigations are recommended. Lean tools could be a promising avenue in reducing lead times.

6.5 Summary of Interventions

The chapter presents a range of possible solutions to address the identified issues causing waste, focusing on innovations in labelling, improvements in communication and forecasting, and adjustments in lead time strategies. Below follows a table highlighting key aspects of each specific intervention.

Intervention	**Why?**	**Benefits**
Digital labelling	Challenges with reuse and shelf-life extensions with physical labels.	Easy real-time updates of labels would increase possibilities of reuse and shelf-life extensions. Reduced quality issues.

FEA as a Communications Tool	A promising tool, currently underutilised and inconsistently applied across studies, could provide more benefits.	By standardising and furthering communication forecasting could be improved, reducing risk of poor allocation and expiry. Also allowing for quicker study adjustments.
Advancing the Use of Digital Forecasting Tools	Current forecasting tools are not fully utilised due to a lack of understanding and systematic application.	Standardising use can lead to more accurate predictions and planning, reducing overproduction and waste. Educational material could be vital in standardisation.
Investigate Lead Time Reduction	Currently long lead times in many processes, increasing risks of product expiration.	Shorter lead times could increase the likelihood of use before expiry, reducing waste and costs.

7. Conclusion

This research has comprehensively explored the multifaceted issues contributing to waste within the clinical supply chain, offering a critical lens on the potential solutions that could mitigate these challenges. Central to our findings is the pivotal role of digital labelling, which could be a promising avenue of innovation for enhancing efficiency, sustainability, and accessibility in the clinical supply chain. By facilitating the ease of updating product information, such as expiration dates and study details, digital labelling can significantly reduce waste and enable the reuse of products across multiple studies, thereby aligning with environmental sustainability goals and economic viability.

However, the implementation of digital labelling is not without its challenges, primarily the uneven access to the necessary digital tools across different global regions. This discrepancy underscores a broader issue of equitable access, necessitating a nuanced, region-specific approach to digital labelling adoption. In areas with widespread digital access, digital labels could revolutionise supply chain management, while traditional labelling might remain pertinent in less digitally accessible regions. This balanced approach seeks to leverage technology to reduce waste without exacerbating disparities in access to healthcare and information.

Further, our analysis highlights the importance of improving forecasting and communication within the supply chain through the use of the Forecasting and Expectation Agreement (FEA) and digital forecasting tools. Standardisation and continuous improvement in the use of these tools and agreements can significantly reduce waste by providing more accurate data for supply chain planning. This includes addressing overproduction and excess inventory, two critical waste forms in lean production philosophy.

Moreover, the investigation into lead time reduction offers another avenue to decrease waste, emphasising the need for a more agile and responsive supply strategy. While the study points towards the complexity of operationalizing lead time reduction, it stresses the importance of further, targeted research to identify effective strategies that could complement digital labelling and forecasting improvements.

In essence, the convergence of digital innovation and lean management principles stands as a potent strategy for tackling waste in the clinical supply chain. Digital labelling, alongside enhanced forecasting and streamlined communication, holds the promise of creating a more sustainable and efficient supply chain. However, the success of these interventions hinges on addressing the underlying challenges of digital access and integrating these solutions within a broader, systemic approach to supply chain management. As we look forward, it is clear that a collaborative, multi-stakeholder effort is essential to realise the full potential of these innovations,

ensuring that the clinical supply chain not only minimises waste but also maximises value for all involved parties.

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9. Appendix

Appendix I: Interview questionnaire

A. What are the common reasons for scrapping of product?

B. At what stage(s) of the study lead supply chain do you notice the highest occurrence of waste or scrapping? Can you describe the contributing factors?

C. How are scrapped products currently being managed or disposed of? Are there any efforts towards recycling or reusing these materials?

D. What in general do you see as the driving forces behind waste accumulation in Astra? Are there any recurring issues with processes?

E. Can you describe any existing measures in place aimed at reducing product waste?

   a) How effective do you find these measures?

   b) What measures would you like to see implemented?

F. At what point in the study was it identified that scrapping would occur?

G. At which stage of the study did the scrapping occur?

H. Why was product scrapped during the study in question?

I. What were the primary mechanism(s) associated with the scrapping, i.e. long lead times, or regulatory reasons?

Appendix II: Interview schedule

Foundational interviews

Every week one hour between 11.00 and 12.00 on Fridays was reserved for a meeting with the supervisor from AstraZeneca, Marcus Josefsson. Initially these were interviews aimed at gaining foundational knowledge regarding the clinical supply chain and its sustainability. The first meeting took place on the 23rd of January 2024 and was longer than the others, from 11.00 to 14.00, as it was an introductory meeting with more material to go over. The last meeting took place on the 3rd of May 2024. The meetings were primarily conducted on AstraZeneca's site in Mölndal but were at times held digitally when circumstances called for it.

Beyond the meetings with Marcus Josefsson two further foundational interviews were held.

The first was with Britta Claesson who works with Study Design. The interview took place Friday the 9th of February 2024. From 11.00 to 12.00. The interview was held digitally using Microsoft Teams.

The second was with Johan Sturesson who works in the Strategy department. The interview took place on Friday the 16th of February 2024. From 9.00 to 10.00. The interview was held digitally using Microsoft Teams.

Empirical interviews

As the interviewees were promised anonymity, no names will be declared to specific interviews.

Interview #1: Wednesday the 13th of Mars 2024. From 11.00 to 12.00. The interview was held digitally using Microsoft Teams. The interviewee worked in BioPharma.

Interview #2: Thursday the 14th of Mars 2024. From 12.30 to 13.30. The interview was held digitally using Microsoft Teams. The interviewee worked in Oncology.

Interview #3: Friday the 15th of Mars 2024. From 11.00 to 12.00. The interview was held digitally using Microsoft Teams. The interviewee worked in Oncology.

Interview #4: Wednesday the 20th of Mars 2024. From 13.30 to 14.30. The interview was held digitally using Microsoft Teams. The interviewee worked in BioPharma.

Interview #5: Tuesday the 9th of April 2024. From 9.30 to 10.30. The interview was held digitally using Microsoft Teams. The interviewee worked in Oncology.

Interview #6: Thursday the 11th of April 2024. From 16.00 to 17.00. The interview was held digitally using Microsoft Teams. The interviewee worked in BioPharma.

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