Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
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Implementing technological advancements into the hospital warehousing operations

Master's thesis in Global manufacturing management
Supervisor: Fabio Sgarbossa
June 2023

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Preface

This report was completed as a thesis project for the master study program "Global manufacturing management" at the Norwegian University of Science and Technology (NTNU), production management group within the department of Mechanical and Industrial Engineering.

The objective of this paper is to contribute to knowledge regarding the hospital warehousing operations and study the effects and challenges of implementing technological advancements to these infrastructures.

I would like to thank my supervisor, "Professor. Doctor. Fabio Sgarbossa", professor of industrial logistics, leader of the production management group, and head of the logistics 4.0 laboratory at NTNU, for his valuable support, feedback, guidance, and motivation throughout the semester. He has been a source of inspiration and useful insight, which has had a significant impact on the development of this project. I am also grateful to the "NTNU production management research group" for their assistance, seminars, and feedbacks.

A special thanks to the industrial partner of this project, "st.olavs Hospital logistics center" and the entire warehouse team, managers, and operators, for their contributions to the success of this project.

I would also like to thank my friends and colleagues for their continuous support and for sharing the day-to-day activities of developing this master thesis with me. And a special greeting, thanks, and gratitude to my family for their support, motivation, and belief in my abilities and potential throughout my studies.

Trondheim, Norway

Mai 30th, 2023

Elmehdi Belabied

Summary

The covid19 pandemic, which truck the world in 2020, demonstrated the importance of having a solid sanitary system and the vitality of such sector for the people's safety and health security. The warehousing operations and logistics are one of the most important and critical parts of the health care system supply chain. With geographical challenges, strict time schedule, and diverse choice of suppliers, the warehousing operations of the hospitals in Norway, specifically in Trondheim, are under more pressure than ever, and the need to increase efficiency and improve performance is greater. As a cost reducing and performance improving plan, the trend in the medical warehousing operations is to implement technological advancements.

The theory and literature appear to lack specifications regarding the hospital warehousing operations. This has a negative impact on the way of implementing technological advancements into the hospital warehouse.

The objective of this master thesis is to investigate the challenges and the effects of implementing new technologies into the medical warehousing operations. The outcome of this investigation will help to build a framework to implement technological advancements in a proper and more convenient way to the hospital warehouses.

Under the title of "Implementing technological advancements into the hospital warehousing operations", this research project studies the following research questions :

- RQ1: What are the challenges of implementing technological advancements into the hospital warehousing operations?
- RQ2: What are the effects of implementing technological advancements into the hospital warehousing operations?
- RQ3: What is the convenient way to implement technological advancements into the hospital warehousing operations?

The research design of the research project is a literature study first, of the most relevant topics, combined with a case study of the logistics center of St.Olavs hospital in Trondheim, Norway. Both the literature study and the case study were used to

build up the discussion answering the research questions and the objectives of the master thesis.

The output of this master thesis is a framework of implementing technological advancements into the hospital warehousing operations. Based on the investigation of challenges, effects and specifications of the medical warehouse, the project dresses a road map and a framework that should serve as a guide line for any potential project of implementing technological advancements in the warehousing operations in general and the hospital warehouse more specifically.

Sammendrag

COVID-19-pandemien i 2020 viste hvor viktig det er å ha et robust sanitærsystem og hvor viktig det er for folks sikkerhet og helse. Logistikk og lagerstyring er blant de viktigste og mest avgjørende komponentene i helseforsyningskjeden for omsorgssystemer. Sykehus i Norge, spesielt i Trondheim, opplever mer press enn noen gang på grunn av geografiske vanskeligheter, streng tidsplan og et mangfoldig utvalg av leverandører. Det er også et større behov for å øke effektiviteten og forbedre ytelsen. I tillegg er medisinsk lagerdrift i ferd med å bruke teknologiske fremskritt for å spare penger og forbedre ytelsen.

Det ser ut til at teorien og litteraturen mangler en beskrivelse av sykehusets behov og krav til lagerdrift. Dette påvirker hvordan man implementerer teknologiske fremskritt i sykehusets lager på en riktig og praktisk måte.

Målet med dette masteroppgaveprosjektet er å lage og kle en modell av et lagerhus for sykehus og bestemme hvor vanlig det er for et typisk lager. analysere problemene og virkningene av å bruke ny teknologi i medisinske lageroperasjoner. Denne undersøkelsens funn vil bidra til å bygge et rammeverk for å implementere teknologien til sykehusets lager på en mest mulig effektiv måte. Følgende forskningsspørsmål tas opp i dette forskningsprosjektet med tittelen "Effektene av å implementere teknologinologiske fremskritt til sykehuslageret":

- Forskningsspørsmål 1 : Hva er utfordringene med å implementere teknologiske fremskritt på sykehuset lagerdrift?
- Forskningsspørsmål 2 : Hva er effekten av å implementere teknologiske fremskritt på sykehuset lagerdrift?
- Forskningsspørsmål 3 : Hva er den praktiske måten å implementere teknologiske fremskritt på sykehuset lagerdrift?

Forskningens design inkluderer først en litteraturstudie om de mest aktuelle temaene, og deretter en casestudie om logistikksenteret til St.Olavs regionsykehus i Trondheim, Norge. Forskningsspørsmålene og masteroppgavemålene ble besvart gjennom bruk av både litteraturstudiet og studiecasen.

Resultatet fungerer som et grunnlag for å bruke teknologiske fremskritt i sykehusvareboligdrift. Prosjektet skaper et veikart og rammeverk som skal fungere som retningslinjer for å implementere teknologiske fremskritt i lagervirksomhet generelt, og spesielt i sykehuslageret, etter å ha undersøkt problemene, effektene og spesifikasjonene knyttet til medisinsk lager.

Acronyms

KPI: Key Performance Indicator
WIP: Work in our process
DC : Distribution center
WMS: Warehouse Management System
AGV: Automated Guided Vehicle
VLM: Vertical lift module
AMR: Autonomous Mobile Robots
AS : Automated storage
RS : Retrieval Systems
CPS: Cyber physical systems
IoT: Internet of things
IoS: Internet of services
ERP: Enterprise resource planing
APS: Advanced plannig scheduling
GDP:Gross dynamic product
GVA: Gross value added
EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization
CAPEX: Capital expenditure
SEO: Search Engine Optimization
SKU: Stock keeping units

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1 Introduction

The first section of this chapter discusses the practical and theoretical motivation and background of the research areas of interest. The research objectives and research questions of this project are followed by a dive into the research scope. Finally, the thesis structure is presented, along with a brief description of each chapter.

it is relevant to mention that some of the information stated in the literature study and the case study are out of the specialization project (TPK4530-Autumn 2022) research paper named "Characteristics of hospital warehouses and technological advancement possibilities" by Elmehdi Belabied author of both papers.

1.1 Background

Warehouses are the points in the supply chain where product comes into contact, even if somewhat briefly. This necessitates both physical space and time (person-hours), both of which are expensive. (Bartholdi, Hackman,2019). Labor, capital (both material and technical), information systems and software, as well as numerous management and material handling processes, are all expensive. Because of the different types of products received and stored, the structure of the supply chain, and the various stakeholders in the production lines, operations vary from warehouse to warehouse.

Warehouses can be categorized by type, which is primarily defined by the customers they serve, and the nature of product they work with (Bartholdi, Hackman, 2019). These are some of the main and more important distinctions of warehouses :

- **Retail distribution center:**
  This type of warehouse provides merchandise to retail stores. The distribution center's immediate customer is a retail store, which is either a regular or captive customer, receiving shipments on regularly scheduled days. A standard/basic order may serve many stores; the product flow in this case can be described as massive. The types of products stored depend on the market and customer demand, but because orders are known ahead of time, it is possible to have good scheduling and consistent forecasting, which helps in better workforce planning. It is important to note that many products may be pushed from the distribution center to the stores, particularly for marketing purposes.

(Bartholdi, Hackman, 2019)

- **Service parts distribution center :**
  This is one of the most difficult warehouses to manage. The warehouse is dedicated to storing spare parts for expensive capital equipment such as automobiles, airplanes, computer systems, or medical equipment... implying that this facility is a significant investment, and the inventory is critical and costly. The total activity in the distribution center (DC) may be statistically predictable due to the large number of parts, but the demand for any particular is relatively small and thus difficult to predict. This has a direct impact on the demand variance, which can go either way, too high or too low. To deal with this, these warehouses are supposed to keep a consistent safety stock, especially since replenishing parts to the warehouse can take a long time. Actually, there is sometimes as much safety stock as cycle stock, so these situations require a lot of space. As a result, a larger storage area is required. However, this increases travel distances and makes order picking more difficult and inefficient. (Bartholdi, Hackman, 2019)

- **Catalog fulfillment or e-commerce :**
  This type of warehouse is becoming increasingly popular as the popularity of online shopping and e-commerce grows. Basically, the orders are small, consisting of 1-3 items on average, but the difficult part is that there are too many small orders, so the "mass production theory or technique" is no longer applicable, and each small order should and must be handled separately because they are all unique. Because customer orders require and request immediate responses and very short delivery times, the efficiency rate in this type of warehouse is expected to be very high and in harmony with all suppliers and transportation/shipping companies. (Bartholdi, Hackman, 2019)

- **3 PL warehouse :**
  This is the type of warehouse to which a company can outsource its warehousing operations. The 3PL provider may serve multiple customers concurrently in the same facility, gaining economies of scale or complementary seasons that the customers would not be able to achieve on their own. To handle surges in product flow, 3PL facilities can also be contracted as overflow facilities.(Bartholdi, Hackman, 2019)

- **Perishable warehouse**
  This warehouse specializes in handling food, fresh products such as flowers, vaccines, and other products that require refrigeration or specific storage pressure... due to their short shelf life. Such warehouses are distinguished by the fact that products reside within for very limited/short periods of time,

frequently hours. The challenge of storage and space handling in this type of warehouse is very high because refrigeration is so expensive, especially in the current situation with higher energy prices. Inventory management is also difficult due to the requirement to ship product according to FIFO (First-In-First-Out) or FEFO (First-Even-First-Out) (First-Expired-First-Out). Many restrictions on how the products are handled add to the difficulty.(Bartholdi, Hackman, 2019)

It's also worth noting that this type of warehouse is becoming increasingly common in China, Brazil, India, and other rapidly growing countries with rising demand for fresh fruits, vegetables, meat, and dairy products.

There are various types and categories of warehouses, and it is very possible to find a variety of warehouses in one supply chain, making the challenges of coordination and managing the material flow more difficult. As we shall know, the selection of equipments and the organization of material flow are largely determined by :

- Inventory characteristics: like the number of products, different types, size, storage requirements (temperatures, pressure ...)
- Throughput and device requirement: The number of lines and orders shipped per day or working shift.
- The footprint of the warehouse and capital cost of equipment
- The cost of labor

- **Medical Warehouses:**

  The medical warehouses, having the same structure of a normal warehouse, they are made of the five departments of reception: storing,picking, packing and shipping. But these warehouses do have other challenges and difficulties regarding mainly the material handling conditions throughout the warehousing processes, particularly in the storage conditions. The main factors that should be respected and taken care of during the hospital's warehousing operations are temperature, pressure, and sterilization. The security measures are much stricter and more stringent. Due to the nature of some products, an anti-fire room well equipped to store easily burnable products is also required. (Herbet, Davis, 2005)

  On the other hand, the medical supply chain has different criteria for storing policies, and the safety stocks of medical warehouses are much higher than those of regular one. The inventory carrying costs are not considered because the products must be kept in stock even if they are not used or sold. At the same time, the relationship between the warehouse and the supplier is more

critical and strict in this situation, and reliability is vital because it involves products that have a direct impact on human life/health. (Frazelle, 2001) The quality of the performance and the accuracy of the picking and orders handling is stricter and so is the margin error.

Warehouses are an essential component of supply chains. In terms of costs, they account for roughly 20 per cent of total logistic costs. (Herbet, Davis, 2005) In terms of service, distribution centers and warehouses are critical to achieving a better customer service, because they are frequently the final point in the supply chain for order assembly, value added services, and dispatch to the customer. (Frazelle, 2001)

In the medical field for instance and with such high stakes and ongoing challenges, maintaining a high level of efficiency and providing a high level of service are vital, but also difficult to achieve. Implementing and utilizing technological advancements is one solution for making warehouse operations more efficient.

1.2 Research objectives and questions

Previous research papers and theses have primarily focused on investigating the various technologies that can be applied to warehousing operations in general, from a very broad and general perspective in terms of the field of work and the types of products handled in the warehouse. The process of incorporating new technologies into warehousing operations undoubtedly has its own set of consequences and effects on the warehouse as a working unit.

The primary goal of this master's thesis is to investigate and identify the challenges and the effects of implementing new technologies into the warehousing operations, with a specific focus and narrow scope on the hospital logistics centers (hospital warehouses). The following goal will be to construct, based on the study's and investigation's findings, a framework for properly implementing technological advancements to the medical warehousing operations, including factors to consider, elements to include and keep in mind, as well as a variety of common mistakes to avoid and good habits to implement.

This framework will serve as a road map for the warehouse managers in general, and the hospital warehouse managers in particular, during the implementation of a new process, integration of new technologies, or adoption of a new/different way of performing tasks.

The following research questions will be the focus of this master thesis project :

- **Research Question 1:** What are the challenges of implementing technological advancements into the hospital warehousing operations?

  Determine the main barriers to the implementation of new technologies into the hospital warehousing operations from various perspectives.

- **Research Question 2:** What are the effects of implementing technological advancements into the hospital warehousing operations ?

  Investigate, quantify, and assess the potential effects and consequences of incorporating new technologies into the hospital warehousing operations.

- **Research Question 3:** What is the convenient way to implement technological advancements into the hospital warehousing operations ?

Create a framework that will allow for a more stable process of implementing technological advancements. This will serve as a guideline for the management team throughout a project of implementing technological advancements in the warehousing operations in general and more specifically the hospital one.

The research questions are expected to lay the foundation for the framework's development, as well as provide a clear understanding of the topic in conjunction with the case study of the hospital warehouse.

1.3 Research scope

A warehouse is a physical location where goods and materials are kept until they are distributed to their final destination. It acts as a link in the supply chain between suppliers and customers, providing a centralized location for inventory management, order fulfillment, and transportation consolidation. Warehouses are critical components of modern supply chains, allowing businesses to better manage inventory, reduce lead times, and provide better customer service. (G.Kay, 2015)

Because of the nature of warehouses in the supply chain, as well as their importance and direct impact on the customer especially in the medical sector, they are subject to all optimisation, automation, and development processes in order to achieve the best performance and the high service level required. "the implementation of the technological advancements into the hospital warehouse" is the thesis's main and first research scope.

The scope of this paper is structured around the relevant technological advancements for hospital warehousing operations, and delves into all the various possibilities they can bring in term of performance.

Implementing technological advancements into an existing process or system is fraught with difficulties, as the change and impact can be profound on multiple levels. Therefore, the scope of this project will delve further into the challenges and the effects of implementing these technologies in the context of the medical warehousing operations.

On the other hand, due to the sensitivity of the hospital warehousing operations and their direct impact on the health care system, the margin of error is extremely narrow and must be minimized to the greatest extent possible. As a result, the scope of this paper will delve into the potential risks of implementing technological advancements and the good habits to follow for a smooth transition.

Due to a lack of research papers and studies in the theory regarding hospital warehousing operations in particular, the scope of the study has been set to remain open to general warehousing operations in the literature study, with the case study used to narrow the scope down to the medical field and the hospital warehouse.

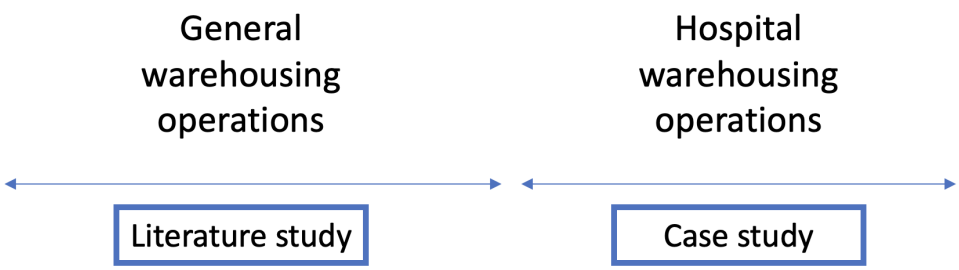

Figure 1: Research scope of the research paper

1.4 Thesis structure

This research thesis, will adopt the following structure:

- **Chapter 1: Introduction**
  The introduction of this paper presents the background and motivation of the project and its topic, the research objectives, the research questions, the scope of this study, and concludes with the thesis structure. In this way, it clarifies the line of reasoning and the strategy used to construct this master thesis.

- **Chapter 2: Methodology**
  The study and methodology chapter presents and lists the reasons why the research approach was chosen, as well as how the literature review and case study were carried out.

- **Chapter 3: Literature Study**
  This literature review for a master's thesis presents relevant research that answers the research questions. The literature review will focus on general warehousing operations (due to a lack of articles regarding the hospital warehouses), as will be detailed in a later stage of this report. This chapter begins with a study of the various possible technological advancements into the warehousing operations, then delves into the challenges that the implementation of technological advancements into warehousing operations brings. A thorough investigation of the potential effects of such implementation on warehousing operations, with the KPIs (Key performance indicators) introduced as part of the study . The literature also delves into best practices and common pitfalls to avoid when incorporating technological advances. This section will aid in answering the third research question by constructing a framework for implementing technological advancements into the medical warehousing operations.

- **Chapter 4: Case study**

  The case study narrowing the scope down of the study to the hospital warehouse field is introduced in this chapter. The purpose of the study case is to provide a detailed description of the hospital warehousing operation, including its structure, layout, and material flow. The study delves into investigating the challenges of incorporating technological advancements into hospital warehousing operations. Furthermore, the effects of this implementation are evaluated based on the outcome of the study case and the investigating study. Finally, the main outcomes of the study case are summarized at the end of this chapter.

- **Chapter 5: Discussion**
  The discussion chapter summarizes the main findings of the research and critically examines the literature review and the case study. This will serve as the foundation for answering the three main research questions listed in the first chapter of this research project.

- **Chapter 6: Conclusion**
  The conclusion of this thesis, discuss the extent to which the research questions and objectives have been answered and fulfilled, as well as the project's limitations and future research possibilities.

The graph below depicts a detailed mapping of the thesis, as well as how each research question is approached and answered in this report:

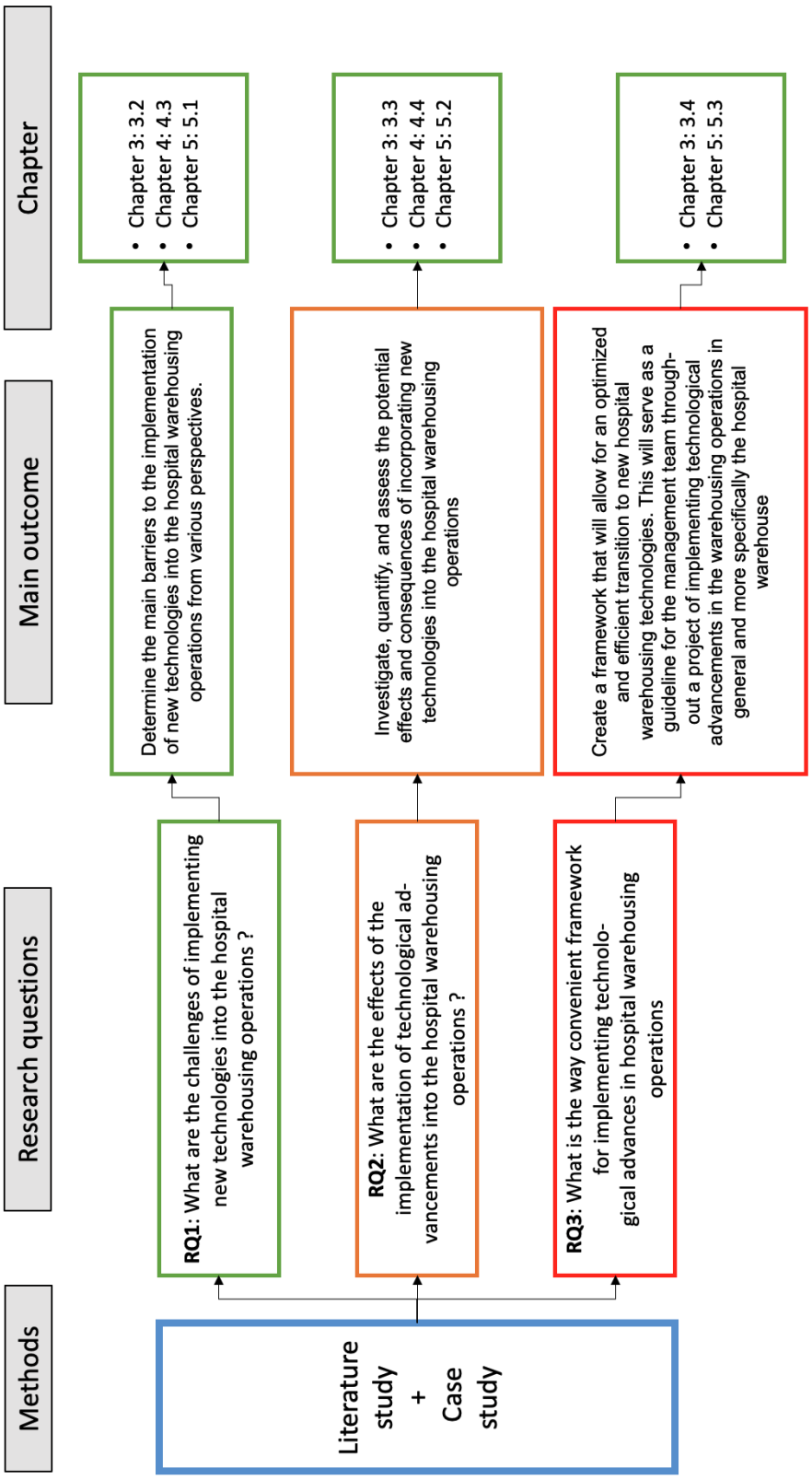

Figure 2: Scheme of the thesis structure

2 Research Methodology

The methodological approach for this thesis is presented in this chapter. This includes justifying the research methods used to answer the research questions and objectives, as well as describing how the research methods were used to guide the research process. Finally, an explanation of how the research methodology contributed to the thesis structure is provided.

Knowledge production in the fields of science, technology, and business is accelerating at a breakneck pace while remaining interdisciplinary. This makes it extremely difficult to keep up with the state-of-the-art and to be at the forefront of research in order to assess the collective evidence in a specific area of technological and scientific research. (Journal of business research Abstract). This is why the literature review as a research method is more important than ever, and it is the first research method used in this Master Project. Project execution, on the other hand, can take a quantitative, qualitative, or mixed approach. And the more concrete and real-life relevant the topic, the more concrete/physical argument is required, which is the main rule of "the case study" research methodology. (Yin,2013)

This project is being led as a hybrid of quantitative and qualitative research, with the goal of better understanding the effects of technological advancements on hospital warehousing operations, as well as the challenges that come with this transition. In addition, the results of both the case study and the literature review were used in this project to create a practical framework for better implementation process of technological advancement into the hospital warehouse.

Logic of argumentation

There are three approaches to developing a logical argument: deduction, induction, and abduction (Karlsson, 2010). The approaches differ in the order in which three components are combined: rules, observation, and result. Karlsson claims that rules are derived from theory, observations are based on empirical evidence, and results are generated through data analysis. Figure 3, depicts how these components are combined in three approaches. (Karlsson,2010)

	Deduction	Induction	Abduction
Sequence	Rule ↓ Observation ↓ Result	Observation ↓ Result ↓ Rule	Result ↓ Rule ↓ Observation

Figure 3: The logic of argumentation (Karlsson,2010)

This thesis' research is based on an iterative approach that combines existing literature and empirical observations. Because there is little research in the field of interest (hospital warehouses), the emphasis has been on discovering important features not previously studied in the literature rather than confirming existing theory. This limits the research to an inductive rather than a deductive argumentation approach.

2.1 Literature study

A literature review is a summary and an overview of previously published works and projects on a specific topic, a full scholarly paper, a research project (as it is the case here) or a section of a scholarly work. The purpose of a literature review is to provide the project with a general picture of the existing knowledge on the topic under consideration. A good and well conducted literature review can ensure that the right research questions are asked and that the right theoretical framework and/or research methodology is chosen. A literature review in particular, serves to situate the current study within the body of relevant literature and to provide context for the reader. (Baglione, 2012)

There are many and different approaches to the literature review: Approach systematic, semi-systematic and integrative (Figure 4). All the four methods are relevant for this master project.

Consideration of prior, relevant literature is essential for all research disciplines and all research projects. (Wohlin,2014)

Approaches to literature reviews.

Approach	Systematic	Semi-systematic	Integrative
Typical purpose	Synthesize and compare evidence	Overview research area and track development over time	Critique and synthesize
Research questions	Specific	Broad	Narrow or broad
Search strategy	Systematic	May or may not be systematic	Usually not systematic
Sample characteristics	Quantitative articles	Research articles	Research articles, books, and other published texts
Analysis and evaluation	Quantitative	Qualitative/quantitative	Qualitative
Examples of contribution	Evidence of effect	State of knowledge	Taxonomy or classification
	Inform policy and practice	Themes in literature	Theoretical model or framework
		Historical overview	
		Research agenda	
		Theoretical model	

Figure 4: Approaches to literature reviews

In this paper, the search for literature was conducted using the following databases: Scopus, NTNU Bibsys and google scholar. Some relevant Papers and Books were also recommended from the supervisor of this master project "Prof.F.Sgarbossa".

The following key words were chosen and selected to guide and lead the research in order to conduct the systematic research :

Level 1	Level 2
"Warehouse"	"Operations"
	"Logistics"
	"Performance"
	"Hospital"
"Technological advancement"	"Implementation"
	"Performance""
	"Logistics"

Figure 5: Keywords of the research

The words were divided into two levels, with the first serving as a role to introduce and stick to the topic, and the second serving to delve into details and different aspects of the topic. The keywords were combined in order to obtain more and better relevant results.

The process of studying the literature typically begins with a broad overview of existing articles, which are often broad in scope and may only devote a small section to the research phenomenon of interest. Articles discovered through keyword research were read by first scanning the abstract and title. If the title and abstract were found to be relevant for the project, the introduction and conclusion were read to further evaluate the article's relevance. This operation was sorted and organized using an excel file extracted from "NTNU Bibsys" that displayed the article tile,

author, abstract, and source.

Priority and preference were given to articles that directly relate to the scope of the research.

Searching the reference list of a relevant article to find new relevant sources is a common practice. This is known as snowball sampling and is a convenient approach in the beginning of a study when the scope is uncertain. Snowball sampling is a social science approach to operations management research. According to (Wohlin, 2012) This technique yields the same results as a database search, but it is useful for finding related sources and frequently referred articles.

Since the beginning of the literature review process, it became clear that there was little research on hospital warehousing operations in general. It became even more difficult when it came to technological advancements, automation, and the effects on these entities. As a result, articles and papers about warehousing operations were also prioritised. With the study case, the relevance to the medical field will be developed further. It is important to note that the lack of information regarding the hospital warehousing operation is a very good indication of the project paper's relevance and direct relevance to the scientific data Base.

2.2 Case study

The case study is to serve as the empirical part of the project in the case of this research paper. Based on a project of technological advancement implementation into a hospital warehouse, it will back up the theory with concrete and relevant real-life results that are more concrete compared the theoretical side of the literature review. It will also serve as a testing ground for all of the literature research and theories that will be developed.

The study case helps to answer the research questions. It answers directly to RQ1 and RQ2, focusing on the challenges, effects, and consequences. And do indirectly contribute to answering RQ3 by contributing to the insight and construction of the working framework.

Case studies are classified into three types, according to Yin (2013): "Exploratory", "Explanatory", and "Descriptive". Exploratory case studies provide a broad investigation of the phenomenon, with the goal of opening the door to further investigation of the observed phenomenon. Explanatory case studies allow for a surface and deep examination of the gathered data in order to explain causal relationships within the data set. Finally, descriptive case studies take a more narrative approach and aim to describe a phenomenon's natural occurrence.

In the case of this study case, the study case is explanatory since it dives to investigate the effects and the challenges behind the implementation of the new technologies into the warehousing operation in the medical sector.

2.2.1 Case selection:

As previously stated, case research can be conducted in a single case or across multiple cases, depending on the project, its requirements, and the infrastructure available to conduct these study cases. A single case study provides more and better opportunities for depth in research when several contexts within the case are studied concurrently. (Voss et al. 2002)

For this argument, it was decided to concentrate on a single study case and use the single study case approach. This will allow for more concrete and relevant results as well as more in-depth information while studying the topic and research questions of this master's project.

Case selection defines the set of entities from which the research sample will be drawn, and is thus an essential component of developing new theory.(Eisenhardt, 1989). A set of criteria and requirements had to be met by the case study used in this research paper. First, and as previously stated, it was critical that the study case concern a hospital warehouse due to a lack of theory and research papers regarding medical warehousing operations. And, in order to investigate the challenges and effects, a study case where access to the "before" and "after" of the transition to new technologies was required. With also having the possibility of assisting the transition itself.

Secondly, the company should be implementing technological advancements and initiating a transition from manual logistics to logistics 4.0. (Definition: *Logistics 4.0 is informed by industry 4.0 – the shift of the economy towards digitalisation. Supply chain management is complex and dynamic, and the use of digital technologies creates visibility across the value chain and improves performance. In using solutions like data analytics, automated sorting, picking and packing, and drones to inspect inventory, companies can streamline their processes and predict disruptions to manage them. Digitalisation of the supply chain not only helps to reduce inefficiencies, but reduces the logistics industry's impact on the environment.*) (Dhl, 2023). The level of technological advancements in the case study might not reach the full logistics 4.0 with the full automation.

To stay within the scope of the research and the research question, technological advancements do not necessarily imply full automation and industry 4.0, but rather a high level of technology in warehousing operations.

2.2.2 Data collection:

A variety of data collection methods are used for the case study chosen for this project. The main goal is to gain as much knowledge, insight, and relevant information about the project, the warehouse, and the challenges of day-to-day operations as possible.

The first source of information was the data extractions from the warehouse's WMS (warehouse management system) (SAP). The technical team did extract the available data regarding warehouse performance, material flow, and operations handling for the amount of time deemed relevant to draw general conclusions.

It is important to note that the data extractions are performed before and after the implementation of technological advancement in order to investigate the change. Before the implementation it is in the old warehouse of st.Olavs hospital warehouse, and after the implementation, in the new logistics center of the same hospital (more details are provided in the chapter 4: Case study).

Aside from that, the accuracy of the data and information regarding warehouse performance is variable, because the level of technology directly impacts the quality of the information and numerical data available in the warehouse management system. On the other hand, a large amount of data was available for the old warehouse, and performance was optimal when compared to the new warehouse, which was going through a transitional period that impacted data relevance and performance.

The semi-structured interview was the second source of information and data. Many interviews with the management team were conducted as part of this project. The questionnaires (as stated in Appendix A) were provided in advance, and the questions were a mix of close and open questions, allowing for some flexibility in the range of answers and investigating as many challenges and effects as possible. However, it has been ensured that it remains within the scope of the research study.

Visits to the warehouses and conversations with the operators and management team provided a wealth of information too.

Semi-Structured interviews:

Semi-structured interviews are one of the primary methods for gathering empirical data in this case study. This interviewing method is defined and considered to be deployed and used when some knowledge about the topic under investigation is available, but additional details are required or unknown and must be discovered. Semi-structured interviews are known for their adaptability and flexibility in exploring and diving into many issues related to the main topic, potentially uncovering previously unknown issues. However, they are strong enough to steer the conversation during the interview back to the main topic and basic questions. This combination of balance and flexibility is a significant strength of the semi-structured interview.(Wilson, 2013).

But this method has some flaws that we had to be aware of and try to avoid during the interview process. The most frequently mentioned flaws are related to the interviewer and the dependability of the data gathered. The outcome and effectiveness of the interview will be directly dependent on the interviewer's skills and objectivity

when asking questions. Furthermore, the findings may be difficult or insufficient to generalize due to different questions for each interview, and the interviewee may withhold information for a variety of reasons. (Wilson, 2013)

In order to overcome these weaknesses, the interviews called semi-structured should include a "Interview Guide", or what can also be referred to as "Interview protocol". Wilson (2013) suggests that this document should cover the following topics :

- Introduction : This part presents the purpose and the topic of the interview
- Listing : A list for both the topics and the topic related questions
- Suggested follow-up questions (Probes) and notes on what a complete answer is expected to include
- Closing : The closing comment, is to express thanks to the interviewees and appreciate its participation in this survey.

The interview guide and the Final version of the interview guide is available in **Appendix A and B**.

The person interviewed should have knowledge of the planning process and access to shared information (Wilson, 2013). The interviews were conducted with the managers of the warehouses who oversaw the transition from the old to the new warehouse. It was critical to choose the key informants in the event that the company is sought after, as well as the people who would be best informed about the data being researched.

Numerical Data:

In addition to the interviews, numerical Data extraction from the two warehouses studied was received to study the effects of technological advancement on infrastructure performance and process optimization. Because of the low technology level, some of the data for the old warehouse were measured manually, which introduced a margin of uncertainty regarding some of the KPIs. Some assumptions were made, and some mathematical calculations helped to conclude the KPIs that were not measurable directly in the old infrastructure.

The Data for the new logistics center or warehouse was collected directly from the WMS (warehousing management system), with all KPIs measured automatically, the error margin is very low, and the numbers are very accurate.

2.2.3 Data analysis:

Data analysis is central to developing new theories (Eisenhardt,1989). The analysis in this project's study case has been done in two ways, depending on the objective of the analysis. For the part aiming to build a model of the hospital warehouse, and does investigate the material flow, working condition, and identification of the relevant KPIs, it has been more of an analysis of the data collected from the warehouse and the theory, in order to build the required answers. However, when it comes to the investigation, a thorough comparison of the numbers and performance between the two warehouses or the two situations (before and after the implementation process) has been made.

The majority of the analysis and calculations for the data treatment and calculation section were done in Microsoft Excel. Matlab and python were also used to obtain the most accurate results for the distribution and correlation of some variables and KPIs. The data gathered was structured according to the factors identified in relation and correlation to the research questions. The data is displayed on figures and graphs.

2.2.4 Quality assessment:

A quality assessment considers the structure and content of the research methodology (Karlsson, 2010). The quality of an empirical study can be assessed using four criteria: construct validity, internal validity, external validity, and reliability (Yin, 2013). Internal validity is primarily applicable to explanatory case studies in which causal relationships are to be investigated (Karlsson, 2010), and is thus not included in this quality assessment.

Construct validity refers to how well the collected data reflects and represents the real-world situation. Construct validity can thus be defined as the extent to which the methods used for data collection ensure subjectivity while minimizing objectivity. The main strategy for achieving subjectivity is to use multiple sources of evidence, a technique known as triangulation (Voss et al., 2002). This was accomplished by using direct observations and documents as data sources, as well as input from more than one informant in the case company. Key informants were able to review an interview summary as well as drafts of the case study report.

The extent to which the findings can be generalized to other contexts is referred to as external validity. In this thesis, empirical and theoretical findings are compared to discuss generalizability.

Finally, reliability refers to the degree to which a study can be repeated and yield the same results. Case studies are time and place sensitive, making it difficult to replicate the exact outcome. The use of an interview guide on a consistent basis is a required measure to ensure reliability in semi-structured interviews (Yin, 2013). In case studies, there is a trade-off between efficiency and data richness, according to Voss et al. (2002). The data's reliability could be improved by asking the same question to a large number of people. A large sample set, on the other hand, is more often associated with quantitative research methods than qualitative. Another issue concerning the reliability of the current case study is that the interviews were conducted by only one interviewer. Personal prejudices can influence what is seen, heard, and recorded. To reduce personal bias, case insights were discussed with supervisors on a regular basis.

3 Literature study

This chapter is the result of a review of the literature on the warehousing operations and the implementation of technological advancements. There are five major sections in this chapter. The chapter begins with a presentation of technological advancements in the warehousing operations, including both general warehouses and hospital warehouses. The literature study then investigates the challenges that face implementing such technological advancements , as well as the effects of such project on various levels, in correlation with the objectives of the research paper. The final paragraph does present some best practices and recommendations for optimizing the implementation process, as well as common pitfalls to avoid. Finally a summary of the literature does wrap up the main outcome of this chapter.

It is important to note that the results of the literature review revealed a lack of research papers and projects pertaining to hospital warehouses and their specifications. As a result, the scope of the literature study was broadened to include various types of warehouses (general warehousing operations), and the study case will be used to narrow the scope to the medical field later on.

3.1 Technological advancements in the warehousing operations

The field of warehousing operations is at the forefront of change in an era of quick technological advancement. A dynamic environment of cutting-edge innovations is replacing the traditional image of endless rows of static shelves and manual labor. This first subsection examines the unprecedented wave of technological advancements that are redefining how we manage and optimize warehouses, from artificial intelligence and robotics to the Internet of Things and data analytics. Businesses are embracing these transformative tools to streamline operations, improve inventory management, and provide superior customer experiences as they strive for greater efficiency, cost-effectiveness, and scalability.

3.1.1 Standard warehousing operations

Warehouses are an essential component of supply chains. In terms of costs, they account for roughly 20 per cent of total logistic costs. (Herbet, Davis, 2005) In terms

of service, distribution centers and warehouses are critical to achieving a better customer service, because they are frequently the final point in the supply chain for order assembly, value added services, and dispatch to the customer. (Frazelle, 2001).

In order to maintain a high level of efficiency and provide a better customer experience, warehousing operations can be more optimized and efficient by implementing new technology and automation. This process is known as "implementation of technological advancements".

Warehouse technological advancements are designed to eliminate labor-intensive and time-consuming tasks. As a result, workers are freed up to focus on higher-value tasks such as quality control. (Frazelle, 2001) Overall, there are two types of warehouse technological advancements :

- Digital technological advancements
- Physical technological advancements

Digital technological advancements (or automation if the scale of technology is high) relies on software and electronics to minimize and reduce manual processes while also increasing and improving focus on customers and vendors. There are many softwares that can manage the entire warehouse and provide very general overview, but also specific information and details about all of the factory's operations. A "Warehouse management system (WMS)," is an example of digital automation software. The WMS can substitute and replace all types of manual inventory tracking, and provide more accurate, fast, and efficient information to the warehouse managers as well as customers about the status of their orders, which will have a positive impact on the customer service. (Bartholdi, John J; Hackman, Steven Todd ,2006)

Physical technological advancements, on the other hand, refers to the employment and use of warehouse automation equipment to reduce employee labor. One of the primary reasons for using physical automation is to reduce the physical effort of a warehouse employee. Material handling and carrying can be difficult at times, causing a variety of health issues and challenges that endanger the employees' safety. AGVs, for example, are portable robots that follow along marked lines or wires on the floor, or that use radio waves signals, vision cameras, magnets, or lasers for navigation. They are used to move heavy materials around a large industrial structure, such as a factor or a warehouse. (MECALUX, 2022)

Warehouse management technology trends

The following are a few of the most widespread and important technological developments in warehousing operations:

- **Warehouse Management Systems :**
  As previously stated, warehouse management systems (WMS) are software applications and digital platforms created to aid in day-to-day warehouse operations. These systems enable the managers to control, monitor, and optimize the warehouse key functions. This includes inventory tracking, directing picking and shipping activities, and coordinating material handling equipment. (Conger,2021)
  The primary goal of these software and systems is to ensure that warehouse material flow is as cost-effective and efficient as possible. Among the advantages of using warehouse management systems are:
  Lower labor costs : A WMS can help finding the best workers for the most important jobs. It can even generate schedules automatically, reduce the need for guesswork in labor allocation.
  Improved inventory management : Inventory can be tracked in real time by warehouse management systems. This reduces the likelihood of back-orders and other supply issues.
  Better use of warehousing space : These systems can help reduce wasted space by recommending the best locations for inventory storage. (Bartholdi, John J; Hackman, Steven Todd ,2006)

- **Collaborative Robots:**
  Collaborative robots, also known as "Cobots," are robots designed to work alongside human workers. Cobots are used to reduce errors, increase operating speeds and efficiency, and free up time for other tasks. In fact, a study conducted by Darex, a drill and knife sharpener manufacturer, discovered that Cobots can increase efficiency by 30 %. Cobots can also be used in a variety of warehouse tasks such as packing, picking, palletizing, and inspecting. (Conger,2021)

- **Automated guided vehicles (AGVs) and Autonomous Mobile Robots :**
  AMRs are autonomous robots that can navigate on their own and adapt to changing environments, unlike AGVs which depend on external guidance systems and travel along predetermined routes. While AMRs provide greater flexibility and versatility for managing dynamic warehouse operations, AGVs

excel at structured, repetitive tasks. Both technologies are important for optimizing warehousing procedures, and the choice of one over the other depends on the operation's particular needs and requirements. (Conger,2021) The goal of using these machines is to reduce repetitive tasks such as transporting cargo and products from one location to another. This frees up workers to work on more skilled and complex tasks. Furthermore, handling heavy merchandise by a robot is safer than by a human operator.

Other benefits of using AGVs and AMRs Includes :

Increased productivity and efficiency : these machines set the pace for employees and keep them on track.

Reduced labor : By handling navigation, these machines can reduce the amount of labor involved in material handling.

Lower human error margin : improve the accuracy and reduce losses when handling materials because of guiding workers through each task.

Better scalability : It allows beginning with a few units and scale up based on the operator's performance.

Improved safety : AGVs and AMRs are able to interpret their surroundings and avoid collisions thanks to in-built sensors and cameras. (Conger,2021)

- **Automated storage and Retrieval systems :**

  AS (Automated Storage)/RS (Retrieval systems) store and retrieve cargo in specific areas of a warehouse. These systems are designed to automatically follow established routes and obtain materials. As a result, they may be able to eliminate the need for human workers to carry out these tasks. Depending on the nature of a warehouse's operations, AS/RS systems can be configured in a variety of ways. Cranes, shuttles, vertical lift modules (VLMs), and carousels, among other things, may be included. (Conger,2021)

  Overall, AS/RS technology has different and various benefits including :

  Lower labor costs: Because AS/RS systems eliminate the need for manual labor in material picking and placement, there is less demand for human labor.

  Improved picking accuracy: AS/RS systems greatly improve accuracy by eliminating error-prone manual picking processes.

  Maximized floor and vertical space: AS/RS systems provide a high level of storage density. This is accomplished through the use of compact storage, the elimination of wasted aisle spaces, and the utilization of vertical space.

- **Wearables:**

  Smart glasses with augmented reality, finger-trigger gloves, and GPS-tracking bracelets are a few examples. Each is equipped with smart sensors and is intended to be worn by warehouse workers. The devices are linked to the internet and provide information to help users speed up operations. (Conger,2021)

They can, for example, show the worker how to stock, receive, navigate, ship, and even lift goods without taking your eyes off your work. Wearables also have the following advantages:

Less distracted workers: Wearables eliminate the need for cumbersome paperwork or electronics, allowing workers to concentrate on task selection.

Better efficiency : Wearables assist in reducing the number of "touchpoints" required to complete tasks, allowing workers to accomplish more in less time.

Lower costs : Managers can reallocate labor to other, more critical areas to maximize labor costs because workers can do more in less time. (Conger,2021)

- **Predictive Maintenance:**
  The classic and basic way of maintenance is the reactive maintenance. This is when repairs are only performed when equipment fails. Predictive maintenance, on the other hand, refers to the monitoring of equipment to detect potential flaws before they cause a failure. These systems can then take the necessary preventive measures by scheduling corrective maintenance automatically. (Conger,2021)

  A predictive maintenance software system uses sensors such as acoustic monitoring, infrared thermography, and vibration analysis to connect and analyze data. They can also be linked to business systems such as enterprise resource planning (ERP) software and industrial controls. Predictive maintenance has numerous advantages for warehouses, including:

  Less downtime: Predictive maintenance notifies managers of equipment problems before they cause downtime. A predictive maintenance system, in fact, can reduce failures by up to 90 % .

  Improved workplace safety: Failures in equipment can result in serious and even big safety issues. Workers are better protected if they can be avoided in the first place.

  Increased equipment longevity: If equipment problems are not addressed quickly, they can escalate in severity. Because predictive maintenance alerts managers early, they can address issues that can extend the life of their equipment.

- **Fleet Management Systems:** Fleet management is the monitoring and management of a company's vehicles. Fleet management aims to maximize productivity and efficiency while lowering operational costs. 75% of fleet managers rely on fleet management software and vehicle telematics to run their daily operations, according to estimates. These systems collect and analyze data from vehicle-mounted devices such as speed, engine run time, and fuel consumption. This information can then be used to improve operations and

cut costs. Forklifts are frequently tracked using fleet management systems in warehouses. (Conger,2021)
And doing so can be advantageous in a variety of ways:
Tracking activity: GPS locators are included with fleet management systems. This allows you to easily track the location of the forklifts and the operators within a single or multiple warehouses. This can significantly increase the productivity and reduce errors.

Protecting of the equipment : Security alerts in fleet management systems provide real-time updates on each forklift. The updates can be used to send messages to the operators for immediate follow-up.

Optimizing the workflow : it can track the efficiency of the routes and find ways to improve them with the systems in place.

Maintenance management : Managers can determine when maintenance services are due by tracking hours of usage.

- **Pick-to-light and Put-to-light systems :** Pick-to-light systems employ light devices to direct workers on where to retrieve order items from storage. To begin, the worker simply scans a bar code associated with an order. Then, lights mounted on racking indicate which items to select in order to complete the order. The goal is to eliminate the need for employees to manually review pick tickets, which can lead to more errors and less efficiency. Put-to-light systems, on the other hand, are simply the inverse of pick-to-light systems. (Conger,2021) . Workers begin by scanning an order bar code. After that, rack-mounted lights indicate where the material should be stored. The following are some of the advantages of pick-to-light and put-to-light systems:
  Increased productivity : Pick-to-light systems are estimated to increase productivity by 30 to 50%.
  Improved picking accuracy : Workers are less likely to make mistakes because they do not have to manually determine where to pick or place items.
  Reduced training costs : These systems are simple and easy to use. Training can be completed in as little as 30 to 45 minutes.

- **Voice Picking :**
  Voice picking is a method of assisting warehouse workers in fulfilling orders by using verbal commands. Voice picking systems are typically linked to a warehouse management system or enterprise resource planning software. When an order is received, the voice picking system determines the order's requirements. They will then verbally communicate the information to workers, who will receive commands through a headset. The worker is then directed to the item to be picked and given the quantity to pick. Workers can also communicate with

the system to confirm order quantities and locations. (Conger,2021) . Many advantages can be gained by incorporating a voice picking system into your warehouse, including:

Improved picking accuracy : Because voice picking eliminates much of the manual labor involved in picking, order accuracy will improve.

Better productivity : Employees can concentrate solely on picking rather than juggling paperwork and various electronic devices.

Improved Safety : Workers will be less distracted and thus less likely to cause or be involved in accidents because it is hands-free. (Conger,2021)

3.1.2 Logistics 4.0 and warehousing operations

The industrial sector is a key driver of economic growth in most countries; for example, in Europe, it accounts for approximately 80% of innovations and 75% of exports. (Hofmann and Rüsch 2017) and industry 4.0 enables businesses to achieve massive gains in productivity, dependability, and efficiency in order to satisfy customer needs and thus gain market share. (Degryse 2016)

Logistics 4.0 is based on four key technologies. The first is CPS, an integrated system of communication, computing, and control used in many fields such as motor vehicle manufacturing, transportation, and logistics to connect the physical and virtual worlds. The second technology is mobile internet and IoT technologies, which aid in human-machine interaction and machine-to-machine communication (making things talk), and can easily implement intelligent identification, location, monitoring, tracking, and control. The third technology is cloud computing, which provides several internet services such as software, platforms, hardware, and other information technology (IT) infrastructures at a low cost and high performance over the internet. The fourth technology is "big data and advanced analysis techniques", which are used to process various data types by using new processing methods to produce reliable information quickly, thereby assisting businesses in decision making, improving processes, improving operational efficiencies, and lowering costs. (keliang, Liu, Zhou, 2015)

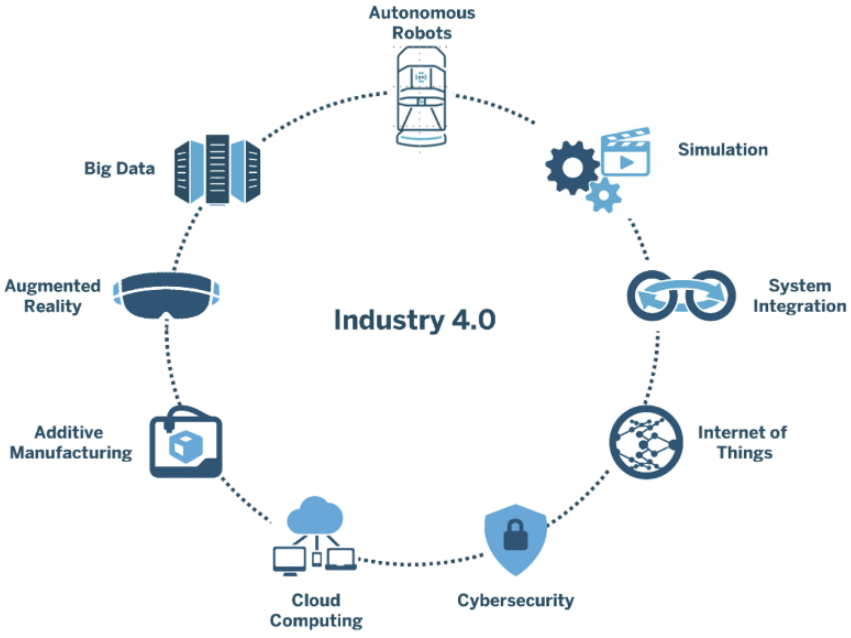

Figure 6: Industry 4.0 drivers

Warehouses can hold thousands of products, so they must be optimally utilized to ensure accuracy and time performance in all functions in order to meet customer demands. Technology in warehousing has the potential to have a significant impact because it can be used to monitor several processes in the warehouse in real time and eliminate manual interference. It can connect everything and thus enable the analysis of the vast amount of data captured from these connections and turn it into insights to support decisions and improve overall performance.

Economic and social impacts :
Reducing human manual intervention and connecting the processes do increase efficiency and save time, which saves money and reduces expenses. Implementing IoT in industry can result in a direct economic and social transformation; a 10% increase in the number of connected machines and objects can result in an annual increase of 0.7% in GDP (gross dynamic product), 0.3% in GVA (gross value added) in services, and 0.9 in GVA (gross value added) in industry. (Rodriguez and Stammati, 2018)

Real-time data and information sharing via the cloud creates enormous value for businesses and consumers by increasing the efficiency of processes and services, lowering costs, improving quality, creating new revenue streams, optimizing inventories, and improving equipment utilization. (Szewczyk, pawel, 2016). IoT and technological advancements have also a significant impact on society; they enable and provide numerous opportunities in the daily working life. And that is mostly due to reducing the human intervention in the manual repetitive processes. It is also important to highlight that the high amount of data generated can be used to develop better and more efficient systems and processes, adapted for the human factor and the work requirements (BCS, 2013).

By reducing human intervention and the error margin, the proposed framework is expected to provide significant benefits to warehouses and supply chains. This is likely to include:

- Higher efficiency
- Ensuring safety of labor and goods
- Reducing risks and accidents
- Reducing operational time
- Optimize/minimize the number of workers per shift
- Improve and increase the efficiency of the packing and the picking processes

- Reduced counterfeiting, fraud, and theft
- Help having better and more accurate Forecast (due to the big amount of available/accurate data)
- Concrete and more suitable decisions are to be made
- Improving a company's overall performance

All of these advantages will boost the warehouse profit and reputation. However, they face a number of challenges when it comes to implementing Logistics 4.0 and technological advancements. With a large number of devices connected and vast amounts of data generated, the warehouses must be concerned about security and privacy, as the data could be hacked and stolen. Furthermore, a lack of technology standards can have a negative impact because manufacturers can design products that operate in any of the disruptive ways online. IoT adaptation necessitates a large amount of energy, so energy demand is regarded as a major challenge of IoT, as is waste disposal, which has a negative impact on the environment and, as a result, on the human lifespan.

3.1.3 Technological advancements and the hospital warehousing operations

A medical warehouse, also known as a hospital warehouse, is a space used to store and hold various types of medical products. These products have a direct impact on people's lives. The medical product should be stored under strict conditions that ensure its quality. (Taylor, Chem, 2001). The environment conditions in the medical warehouse are critical, particularly temperature, pressure, and humidity, because these factors can have a direct impact on the purity, quality, and safety of the medical products. All of these conditions and specifications make the hospital warehouses more difficult to maintain than regular ones used for non-medical products. Preventive measures should be taken to ensure that none of the medical products are harmed by out-of-spec conditions. (Taylor, Chem, 2001)

According to Taylor and chem , medical products should be stored and transported in conditions that ensure their quality. Manufacturers' recommendations for storage temperatures should be followed, which does necessitate the use of specialized storage and transport facilities. (Taylor, Chem, 2001)

What technological advancements for a better hospital warehousing operations ?

In paragraph 3.1.1 of the literature review, there is a list of technological advancements that can be used and implemented to improve the quality and performance of warehousing operations in general. However, when it comes to the hospital warehouse, and taking into account the stated requirements and findings, some of these solutions are more relevant.

- **Warehouse Management System:** Hospital warehousing operation do necessitate a highly developed warehouse management system in order to control, monitor and optimize the warehouse key functions. (tracking, directing, picking, shipping and coordinating material handling equipment). This will allow : lower labour cost, a better inventory management and more efficient use of the storing area. . (Bartholdi, John J; Hackman, Steven Todd ,2006)
  WMS is vital for the hospital warehouse 4 types of the most relevant warehouse management system (WMS) are: Standalone, Supply chain modules, integrated with ERP and cloud based

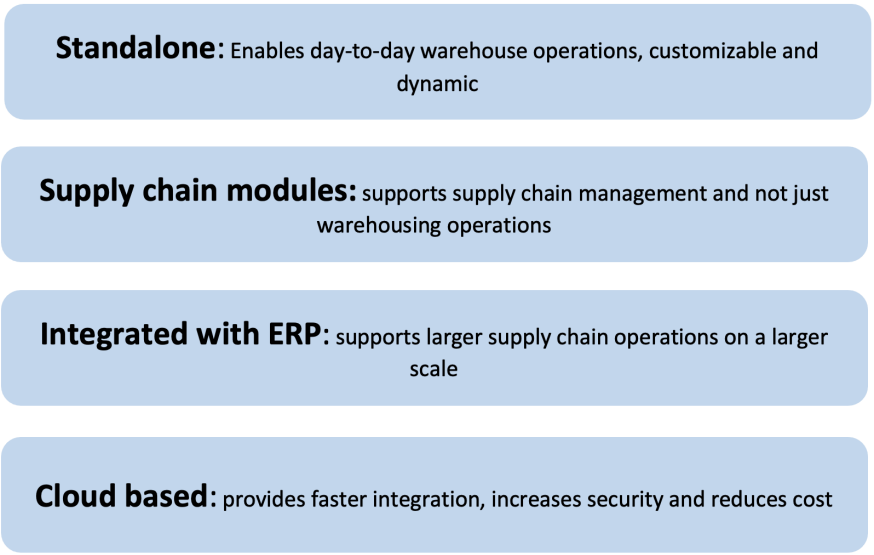

Figure 7: Types of the hospital WMS

- **Picking process:** Implementing a wearable, such as smart glasses with augmented reality, finger-trigger gloves, or GPS tracking bracelets, can directly improve the picking process. These technologies assist the picker in finding the correct item faster and reducing margin error, resulting in improved efficiency, faster picking time, and a lower return rate. This will allow a higher picking accuracy, vital factor for the hospital warehouse. Because the WMS can manage the storing process, it can also provide the picking list with the right picking spots and generate picking lists that optimize the picking process and the distances between the different products. (Conger,2021)

- **Material flow :** A big step up would be the implementation of automated guided vehicle as a transporting tool of heavy materials around the warehouse. There are many types of AGVs based on the navigation techniques: Wired, Guide tap, laser target navigation , inertial (Gyroscopic) navigation, Natural feature (natural targeting) navigation, vision guidance, Geo guidance. The path selection is usually selected by using : the frequency select mode, path select mode or magnetic tape mode.

Figure 8: Example of an Automated guided Vehicle

- **Storing units :** One of the most relevant and efficient technologies to improve the storing area management and have a very setp up regarding the picking accuracy and the picking speed, is the Vertical lift modules (VLMs). A vertical lift module (VLM) is an enclosed system that consists of two columns of trays with an inserter/extractor in the center. The VLM insert/extractor automatically locates stored trays and retrieves trays from both the front and back of the unit with a push of a button and delivers them to the operator at an ergonomically positioned pick window. Designed to deliver stored items to the operator and eliminate walk and search time, the VLM can increase productivity up to 2/3. (mhi,2022). The features that the VLM provide have a direct benefits and impacts on the warehousing performance :

Feature	Benefit
Compact design & tray height optimization	Save up to 85% Floor space
Delivers items to the operator	Improve productivity by 2/3
Integrates with pick-to-light technology	Increase Accuracy up to 99.9%
Locking Door Software provides password protection & transaction Tracking	Secure product Storage
Safety light curtain with emergency stop	Operator safety
All items delivered to an ergonomic work counter	100% Ergonomic access
High MTBF Rate Emergency hand crank	Superior reliability with 24/7 Access

Table 1: Features and benefits of the VLMs (mhi,2022)

One of the common and famous VLMs in the hospital warehousing operations is the "Kardex company VLM". The compact and dependable intralogist-

ics solutions from Kardex provide high-density storage in a small footprint. Kardex helps meeting the storage requirements when combined with efficient and ergonomic storage and retrieval processes. Kardex systems result in significantly better storage space utilization and lower storage costs. Combined with an optimised material flow and adequate warehouse management system (WMS), this technology ensures quick and effective process control. (Kardex, 2023)

Figure 9: Kardex Storage system

The Benefits of the Kardex storing system can be listed as the following:

Flexible and individual solutions: The modular systems help answering the various demand facing the logistics location and more specifically the warehousing operations. (Kardex, 2023)

High density: High-compact storage and optimal use of available space lead to maximum storage capacity and save valuable resources. This allows more flexibility and expansion plans in the other departments of the warehouse. (Kardex, 2023)

Accurate: WMS software coordinates material handling and scheduling and ensures inventory is accurately stored, managed, and available. (Kardex, 2023)

Cost effective: reduces the personnel resources and costs of storing. (Kardex, 2023)

Service Oriented: This solution provides a holistic and modular solution to ensure the warehousing operations work effectively. (Kardex, 2023)

secure: Access restrictions protect valuable goods. (Kardex, 2023)

3.2 The challenges of implementing technological advancements to the warehousing operations:

The incorporation of new technologies or technological advancements into warehousing operations, as described in the previous chapter, has a direct impact on the various aspects of the operations. Benefits and drawbacks, these direct effects are critical in selecting the best and most convenient technology. However, before seeing the results, there are challenges and summons that must be overcome during the implementation process. This transition from a low to high technology environment is fraught with difficulties at various levels of warehousing operations. In this paragraph, we will go over these challenges in detail and categorize them into three categories: "project management challenges", "technological challenges" and "human factors challenges".

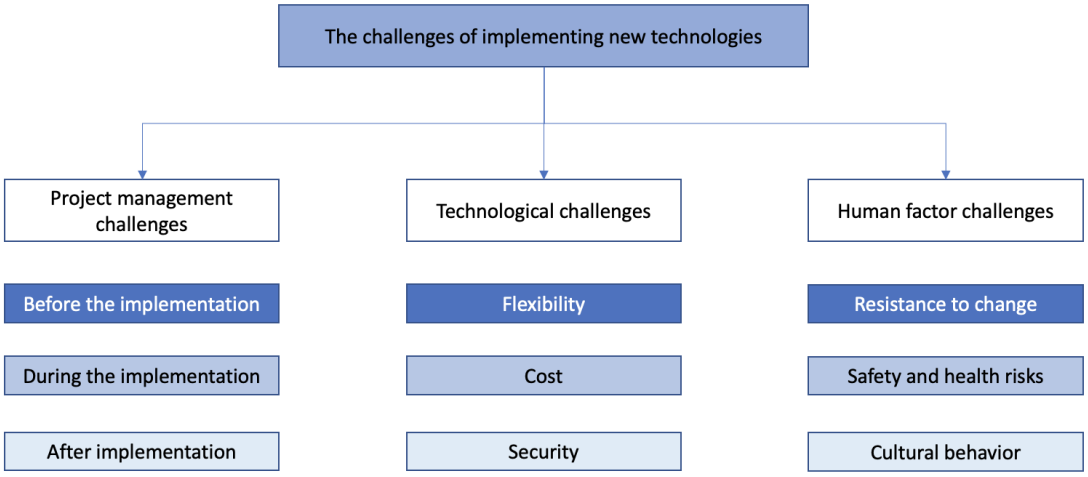

Figure 10: The challenges of implementing new technologies

3.2.1 Project management challenges:

According to P.Baker and Z.Halim, the typical warehousing technological advancement implementation project steps are the following : (Figure 11)

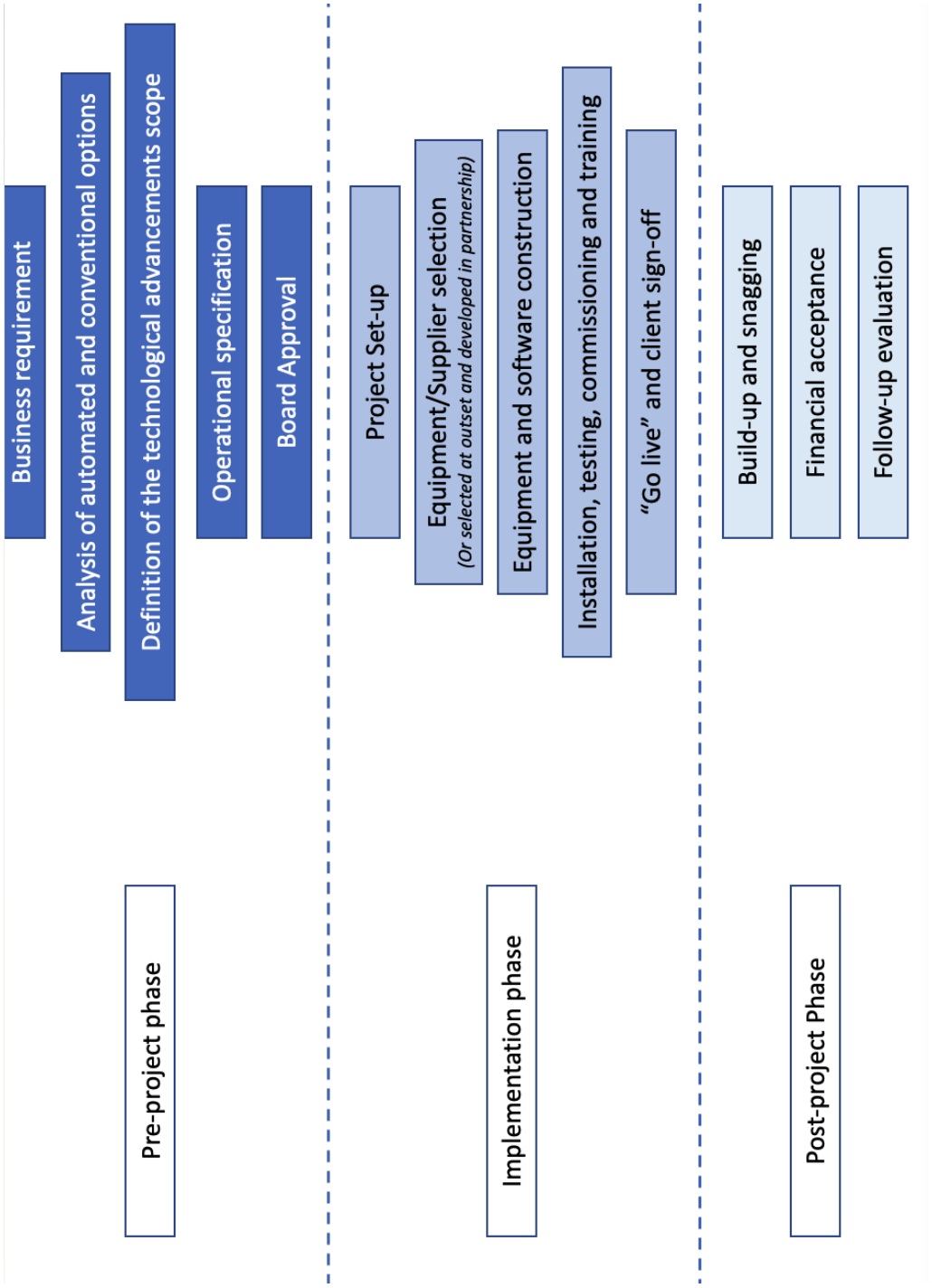

Figure 11: Typical warehouse Technological advancements project steps (P.Baker Z.Halim, 2007)

How Companies and warehouses build the transition project ?

A project typically has a project manager (the person responsible for the day-to-day operation of the project) and a Project Sponsor (who is accountable to the company's senior executives for the project's success). The majority of warehouse automation projects are sponsored at the director level, indicating that the companies considered them to be major projects. This is consistent with the success criteria established for other large supply chain projects, such as major information technology implementation. (Favilla and Fearne, 2005).

The logistics or distribution director is in charge of the majority of the projects. This level of sponsorship corresponds to the importance of the investment and service level, as well as the cross-functional nature of the projects. ("J.Favilla A.Fearne, 2005) Project sponsors in general can be :

- Logistcs/Ditribution Director
- Managing director
- Operations director
- Other Director or Board
- Manager level

The operational specification outlines the project's high-level design. Outlines of automated equipment, buildings, layout, software requirements, operational processes, manual interfaces, maintenance regimes, and capital/operating costs are typically included in this document. (P.Baker Z.Halim, 2007)

The operational specifications of the projects surveyed were typically completed by a combination of in-house staff and an equipment supplier, consultancy firm, and/or a system integrator (for example, a company that takes primary responsibility on the contract for providing a working system that may involve multiple equipment suppliers). All of these companies were sometimes included in the team. In-house personnel were typically drawn from a variety of departments, including logistics planning, operations, and information technology (IT). A third-party logistics provider (3PL) was occasionally included in the team. (P.Baker Z.Halim, 2007)

Warehouse automation projects are typically complex, which lends itself well to computer simulation. This type of simulation can be used to test the operation

and identify potential bottlenecks, as well as to simulate how the operation would continue to operate if a breakdown occurred (for example, to assess the impact of one stacker crane failing in an AS/RS installation).

Suppliers are chosen based on a variety of criteria; each type of business has different priorities and criteria that they prioritize over others.

- Cost
- Experience/track record
- Technology offered
- Relationship with supplier
- Understanding of requirements
- Quality and reliability
- Design and reliability
- Implementation capability
- Various points *(Culture, interest shown, system design capability, software skills, WMS capability, standardisation opportunities, trial systems, late penalty clauses, and follow-up engineering provision)*

To summarize how businesses, particularly warehouses, implement technological advances, they are typically sponsored at the director level, involve multi-disciplinary and multi-company teams, use formal tender procedures, select suppliers based on a variety of selection criteria, and frequently support the design with computer simulation tools. Warehouse automation projects are thus typically established and managed within organizations as major projects.

The impact of the implementation project on the ongoing operations:

In the literature, there is some concern about the impact of technological advancements implementation projects on the ongoing operations. The impact ranges from "minimal" to "moderate or extensive" disruption (as illustrated in Figure 12). A case study conducted by P.Baker and Z.halim on 24 projects of implementing new technologies to warehousing operations found that 11 involved minimal disruption, while 8 experienced severe and extensive disruption. (P.Baker, Z.Halim, 2007)

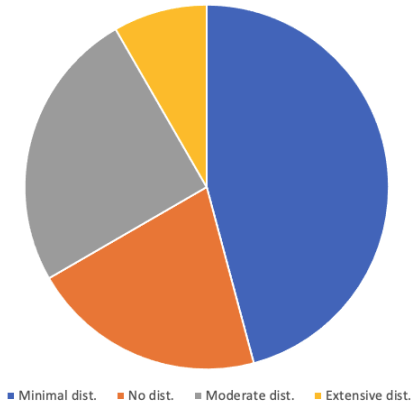

Figure 12: Extent of disruption to the ongoing operation

These findings appear to validate the concern that the technology will not work in the short term. While most automated equipment types have been around for a long time and are thus fairly mature, the complexity of the projects usually involves numerous testing and commissioning issues. Although these are normally resolved, there can be a period when service levels suffer before the designed benefits are achieved. (P.Baker, Z.Halim, 2007)

The manner in which the disruption manifests itself can be diverse. In order of popularity, the following are the primary causes of disruption:

- IT Systems
- Equipment installation
- Consolidation of sites
- Building Construction
- Impact of new technology on new people
- Failure of system to work on time
- Equipment not performing to specification
- Extended hand-over time

These reasons demonstrate the various aspects of automation projects and, as a result, the project's complexity. Delays or problems in any of these areas, as well as

the interface areas between them, may jeopardize the projects' success. For example, installing sprinkler pipes necessitates coordination between building and storage equipment aspects, whereas reading bar codes necessitates coordination between sortation equipment and control software.

One reason for the IT system being such a critical part of the project is the extent of the IT changes that are normally involved with warehouse automation projects, as we stated earlier. Aside from the majority of projects involving new equipment control systems, nearly half of the projects entailed new warehouse management systems (WMS) and the majority entailed at least modifications to the company's transaction systems (e.g., enterprise resource planning or legacy systems). Interfacing between these systems can be a significant challenge in terms of complexity, time, and cost (Higginson and Bookbinder, 2005). In interviews, the critical path in automation projects was frequently cited as software development time. ("J.Favilla A.Fearne, 2005)

The reasons for the Project management challenges:

According to a study conducted by P.Baker and Z.halim (Baker,halim, 2007) on warehouses that implemented new technologies, the two projects that were associated with extensive disruption to ongoing operations were the same two projects that overran budget costs and overran time. As a result, there appears to be a link between these implementation "success" factors. Time overruns, for example, causing disruption, or poorly managed projects resulting in poor performance in each of these areas. An examination of the results reveals two attributes that are related. (Baker,halim, 2007)

The project and implementation timescales are the second attribute that are related to disruption. In comparison to the overall averages of 20 months and three months, the two sites that experienced extensive disruption had an average project time-span of seven months and "ramp up" time of less than a month. (Baker,halim, 2007)

Poor planning and issues in implementation are also major challenges. referring to the design of technological advancements, how they were engineered, and how difficult they are to implement and manipulate. (Baker,halim, 2007)

3.2.2 Technological challenges:

There are several points that businesses must consider when it comes to the technological challenges of warehousing operations implementation. These difficulties can be classified into four categories: flexibility, cost, compatibility with the existing system, and security.

- **Flexibility:** (refers to the ability of new technologies to adapt to changing demands and requirements) Flexibility is an essential aspect of warehousing operations because it allows the warehouse to adapt to changing and variable demand and requirements. Because customer expectations are constantly changing, warehouses must be able to respond quickly and efficiently to these changes or risk negatively impacting customer service and quality in the short and long term (L.Custodio, R.Machado, 2019). And, when it comes to flexibility, warehousing operations face several challenges:

  Infrastructural flexibility:

  Infrastructural flexibility is one of the most significant challenges associated with technological advancements in warehousing operations. As new technologies emerge, they frequently necessitate significant changes to warehouse infrastructure, such as new hardware and software, as well as changes to warehouse layout. For warehouses that are already at capacity or have limited resources, this can be a significant challenge. (L.Custodio, R.Machado, 2019)

  Warehouses must carefully assess the impact of new technologies on their infrastructure and develop a plan for implementing changes to overcome infrastructural flexibility challenges. This plan should include a timeline for implementation as well as a budget for any necessary warehouse infrastructure upgrades or changes. Furthermore, warehouses should think about partnering with technology providers who provide flexible solutions that are easy to integrate into existing infrastructure. (Salgado, C., et al, 2020)

  Workforce flexibility:

  Workforce flexibility is another significant challenge associated with technological advancements in warehousing operations. When new technologies are implemented, they frequently necessitate changes in how employees work, such as new processes or new skills. This can be a significant challenge for warehouses with a workforce that is resistant to change or lacks the skills required to work with new technologies.

  Warehouses must invest in employee training and development to overcome workforce flexibility challenges. This can include training on new technologies

as well as opportunities for employees to learn new skills and take on new roles in the warehouse. Furthermore, warehouses should think about partnering with technology providers who provide user-friendly solutions that require little training and can be easily integrated into existing processes. (Luthra, S., Garg, D., Haleem, A.,2020)

Operational flexibility: Operational flexibility is another significant challenge associated with technological advancements in warehousing operations. When new technologies are implemented, they frequently necessitate changes to the way warehouses operate, such as new processes or workflows. For warehouses with well-established processes and workflows that are difficult to change, this can be a significant challenge. (Gupta, A., Batra, S, 2017)

Warehouses must carefully assess the impact of new technologies on their processes and workflows and develop a plan for implementing changes to overcome operational flexibility challenges. This plan should include an implementation timeline as well as a testing and refining strategy for new processes and workflows. Furthermore, warehouses should think about partnering with technology providers who provide solutions that can be easily customized to meet the unique needs of their operations. (Gupta, A., Batra, S, 2017)

Supply chain flexibility:

Finally, technological advancements in warehousing operations can pose supply chain flexibility challenges. Changes in lead times, inventory levels, or delivery schedules can all have a significant impact on the supply chain as new technologies are implemented. For warehouses that are part of a larger supply chain with multiple partners and stakeholders, this can be a significant challenge.

Warehouses must collaborate closely with their partners and stakeholders to ensure that changes to their operations do not have a negative impact on the supply chain. This could include creating new processes or workflows to improve communication and collaboration with partners, as well as investing in technologies that allow for real-time tracking and visibility across the supply chain. Furthermore, warehouses should think about partnering with technology providers who provide solutions that are easy to integrate into existing supply chain systems and processes. ("Salgado, C., et al.", 2020)

- **Cost:** (Refers to the financial investment required to implement and maintain new technologies)

  Cost Challenges: Implementation and integration costs: The initial implementation and integration costs are one of the most difficult aspects

of adopting new technologies. New system implementations, such as warehouse management systems (WMS), automated storage and retrieval systems (AS/RS), and robotic picking systems, necessitate a significant investment in hardware, software, and personnel. The costs of integrating these systems with existing systems can also be significant, as extensive testing and training are required to ensure that the systems work together seamlessly. (SCDigest,2023)

Mitigation Strategy: To reduce implementation and integration costs, warehouses should conduct a thorough analysis of their current systems and processes to identify areas where new technologies can provide the most significant improvements. They should also think about implementing new technologies in stages rather than all at once, which can help spread the costs out over time. Furthermore, warehouses should collaborate with technology vendors who offer implementation and integration services to help streamline the process and cut costs. (SCDigest,2023)

Cost Challenge: Maintenance and repair costs

Warehouses must allocate resources for ongoing maintenance and repairs once new technologies are implemented. The cost of maintaining and repairing new systems can be substantial, particularly if the warehouse is heavily automated. Because these systems require specialized skills and training, the labor cost to maintain and repair them may be higher than traditional manual labor. (ContainIt, 2022)

Mitigation Strategy: In order to reduce maintenance and repair costs, warehouses should invest in preventative maintenance programs that identify and address potential problems before they become serious. They should also think about partnering with technology vendors who offer ongoing support and maintenance. Warehouses can also invest in training and development programs to ensure that their employees have the skills needed to maintain and repair new technologies.

Cost challenges: Energy costs

New warehousing technologies, such as automated systems and robotics, necessitate a significant amount of energy to operate. This can lead to higher energy costs for warehouses, which can quickly add up. The cost of electricity and other utilities can also vary by location, impacting the overall cost of running a warehouse. (F.Pierce, 2020)

Mitigation strategy: Warehouses should consider investing in energy-efficient technologies such as LED lighting and energy-efficient HVAC systems to reduce energy costs. They can also put in place energy management systems that monitor and control energy consumption in real time. Warehouses can also

collaborate with utility providers to negotiate lower rates and incentives for energy-efficient practices. (F.Pierce, 2020)

Cost challenges: Training and development costs
To operate and maintain new technologies effectively, specialized skills and training are required. This can result in higher training and development costs for warehouses, particularly if they need to hire new employees or invest in additional training programs for current employees. ("J.Lui R.Narsalay, R.Afzal, I.Sharma, D.Light, 2022)

- **Security:** (refers to the risk of cyber threats and data breaches associated with the use of new technologies Also the physical security)

  Cyber-security: As more processes become automated, the risk of cyber-attacks increases. A cyber-attack in a warehouse can disrupt operations, cause data loss or theft, and put sensitive information at risk. For example, hackers could use ransomware to lock down warehouse automation systems, making inventory inaccessible and causing shipping and receiving delays. Warehouses must implement robust cybersecurity measures, such as firewalls, intrusion detection and prevention systems, and encryption technologies, to address this challenge. They must also train employees on how to recognize and avoid cyber threats. (Datex,2022)

  Data security: The sensitive data and information, such as customer information, financial records, financial transactions and inventory details are stored and transmitted digitally in a warehouse environment. The challenge is to protect this information from unauthorized access, manipulation or theft. To ensure data security, warehouse must implement measures and tools such as access control, encryption and backups. They should also monitor data activity on a regular basis to detect, identify and respond to any security breaches. (IWLA,2022)

  Physical Security:

  Although technological advancements are able to help and aid in the automation of the warehouse processes, they also pose new physical security challenges. Automated systems, such as robots, can be damaged or stolen (due to their expensive value), and inventory management drones can be hacked and be used for malicious purposes. The warehouse must implement physical security measures such as security cameras, access control systems (badge, facial recognition ...) and security personnel to address these challenges. The warehouse management team must ensure that all employees are properly trained in security protocols and that all entrances and exits are properly secured. ("ManufacturingLogistics IT",2022)

3.2.3 Human factor challenges:

- **Resistance to change:**

  Change resistance is a common issue when implementing new technologies in warehousing operations. Employees may be resistant to adopting new technologies because they are afraid of losing their jobs, lack trust in the technology, or believe that the technology will reduce their productivity. Resistance can lead to delays in the implementation of new technologies, higher costs, and lower productivity.

  Employers must communicate the benefits of technology to employees and involve them in the implementation process to overcome resistance to change. This can help to build trust in the technology and encourage employee buy-in. Employers can also provide employees with training and support to help them adapt to new technology. (Cascio, W. F., Montealegre, R., 2016)

- **Safety and health risks:**

  The challenges regarding the safety and the health risk are also present and do challenge the implementation of the technological advancements into the warehousing operations. For instance, if the robots and automation are not properly implemented and correctly monitored they can cause a very serious physical injury or accidents. Employees may also face some health risks that are related to this, for instance eye strain or musculoskeletal disorders as a result of prolonged long screen time or repetitive tasks and monotone working habits.

  Employers must conduct risk assessments and put measures in place to reduce the safety and health risks associated with new technologies. This includes adequate training, ensuring proper equipment use and maintenance, and designing workstations that prioritize ergonomics and employee health. (J.Lui R.Narsalay, R.Afzal, I.Sharma, D.Light, 2022)

- **Cultural and behavioral challenges:**

  Employees may face cultural and behavioral challenges as new technologies are implemented in warehousing operations. Adoption of new technologies can alter the way work is done as well as employees' roles and responsibilities. This can lead to resistance to change, confusion, and communication breakdowns.

  Employers must address cultural and behavioral issues by involving employees in the implementation process, providing training and support, and cultivating an environment of innovation and continuous improvement. This can contribute to the creation of a positive work environment that promotes collaboration and adaptability. (Laumer, S., Eckhardt, A., Weitzel, T, 2016)

3.3 The effects of implementing technological advancements to the warehousing operations:

Both "Performance" and "Operations management" are affected by the introduction of technological advancement into the warehousing operations. The effectiveness of the warehouse does directly imply its positive impact on the entire supply chain. Key performance indicators (KPIs) are used to monitor and assess the effectiveness of operations in order to measure performance. They make it possible for the management team to monitor the working unit's efficiency, adherence to all deadlines and schedules, and—most importantly collaboration with the other upstream and downstream components of the supply chain. The daily material flow in the warehouse and the human factor are more important in terms of operations management.

3.3.1 Warehousing operations Keys performance indicators (KPIs):

Due to the increasing complexity of logistic network, the warehouse performance measurement is a very important operation to improve and evaluate the performance of logistics systems.(Emmet,2005) And, in order to improve warehouse performance, it is critical to have tools and methods for measuring and comparing the warehouse's key factors, also known as "Key performance indicators." (KPIs). The warehouse KPIs can be classified into five groups: Inventory, receiving, put away, order management and safety KPIs.

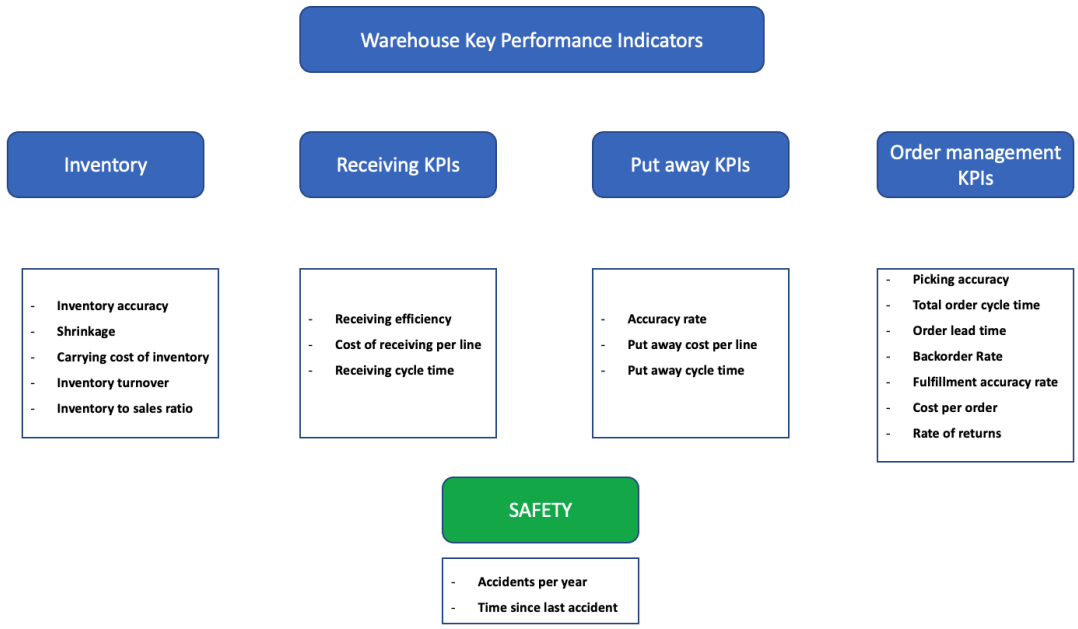

Figure 13: Essential KPIs for warehouse

Inventory KPIs

Inventory KPIs are concerned with the stock of products in the warehouse. They are ideal to help keeping track of how the inventory is evolving. Inventory accuracy, shrinkage, carrying cost of inventory, inventory turnover, and inventory to sales ratio are all inventory KPIs. (Mira,2021)

- **Inventory accuracy :**
  Inventory accuracy refers to the consistency and match between the amount of inventory tracked in the warehouse and the amount physically present. Typically, an internal warehouse management system or inventory management system is used. However, the numbers are not always correct and do not correspond to the quantity of products and the actual inventory physically present in the warehouse. This is due to factors such as damage, miscalculations, supplier shortages, and so on. This KPI indicates whether or not there is a difference between the two values and reflects how accurate the warehouse management system data is. The closer the number is to 1, the more accurate your inventory tracking is. (Mira,2021)

  Formula : Inventory as tracked by system / Physically present inventory

- **Shrinkage:**
  This KPI detects mismatches in inventory accuracy. Excess inventory is defined as inventory that has been recorded or detected but is no longer physically available in the storage area. This could be due to a variety of factors such as theft, damage, or miscalculations. (Mira,2021)
  Formula : (Cost of recorded inventory - cost of physically present inventory)/(cost of recorded inventory)

- **Carrying cost of inventory:**
  The carrying cost of inventory is the total amount of money spent by a company or business on owning, storing, and holding inventory. It represents the amount of time the company can keep inventory before losing money and having to find a new solution for slow-moving inventory and dead stock. Total carrying costs are divided by average inventory costs to calculate carrying costs.(Mira,2021)
  Formula : (Total carrying costs) / (Overall inventory costs)

- **Inventory turnover:**
  The frequency with which inventory is sold is referred to as inventory turnover. A higher value indicates higher sales, while a lower value indicates lower sales.

Inventory turnover can be calculated in two ways: by dividing the average inventory by the number of sales made, or by dividing the cost of goods sold by the average inventory. (Mira,2021)
Formula 1 : (Number of sales made) / (Average inventory)
Formula 2 : (Cost of goods sold) / (Average inventory)

- **Inventory to sales ratio :**
  The inventory to sales ratio is the ratio of "the remaining inventory at the end of the month" to "the sales made during the same month". This value is extremely beneficial to warehouse management teams in general because it allows them to:
  Predict potential cash flow issues before they become a problem, by showing when rising inventory levels coincide with falling sales
  This ratio provides information about the number of products sold by indicating how many items are left in the warehouse at the end of the month. This enables calculating and quantifying how much stock is needed to purchase in order to comfortably continue your sales without backorders.(Mira,2021)
  Formula : EOM inventory balance / Sales for the month

Receiving KPIs:

When a warehouse accepts a delivery of stock that must be processed and eventually stored, the receiving process occurs. Receiving KPIs such as receiving efficiency, cost of receiving per line, and receiving cycle time are used to assess the efficacy of the processes that occurred during this stage. (Mira,2021)

- **Receiving efficiency:**
  This KPI calculates the productivity of the work done by warehouse employees in the receiving area. This assists in deciding whether to implement new training sessions or improve processes. (Mira,2021)
  Formula : (Volume of inventory received)/(Number of staff hours worked)
- **Cost of receiving per line**
  The cost of receiving per line is the total amount spent on receiving a line of products sent to the warehouse by suppliers or vendors. This includes the processes that occur while receiving. This cost should, in theory, decrease over time, indicating more efficient work. (Mira,2021)
  Formula : (Total cost of receiving)/(Total number of items in each receiving line)
- **Receiving cycle time**
  Receiving cycle time is the average time it takes to process received stock, which includes accounting for it, categorizing it, and sorting it. (Mira,2021)
  Formula : (Total time spent on sorting received stock)/(total number of received items)

Putaway KPIs: Putaway is the process of sorting a shipment of delivered products. This should ideally be handled in the warehouse's most convenient and appropriate location. Putaway KPIs can assist in measuring process performance. (Mira,2021)

- **Accuracy rate** The accuracy rate is the percentage of items that are correctly stored the first time. If the ratio equals one, it means there were no errors or mistakes. This rate is calculated by dividing the amount of inventory correctly put away by the total amount of inventory put away.
  Formula: (Inventory put away correctly) / (Total inventory put away)
- **Putaway cost per line** This KPI refers to the cost of storing a complete line of items. This indicator aids in the reduction of expenses associated with putaway processes. It is calculated by dividing the total putaway cost by the

number of line items.
Formula : (Total cost of putaway) / (Total line items)

- **Putaway Cycle time** The putaway cycle time is the average amount of time it takes to store a single item of inventory. Shorter putaway cycle times result in increased warehouse efficiency. Repositioning items in the warehouse and increasing employee productivity can help to cut down on this time.

Order management KPIs

Order management encompasses all processes that occur between the time the business receives a customer order and the time the customer receives the order purchased. Accepting the order, selecting the appropriate product for it, packing them, shipping them to the correct delivery location, and handling post-sales processes such as returns and refunds are all part of the job. As a result, order management KPIs revolve around determining how well each of these processes runs. (Mira,2021)

- **Picking accuracy :** This KPI measures and indicates the accuracy with which items are picked from the warehouse for customer orders, with the goal of improving the overall warehouse efficiency of the Order management processes. Picking accuracy should be as close to one as possible. A value of one indicates that there are no errors.
  Formula: (Total number of orders - Incorrect item returns)/(Total number of orders)

- **Total order cycle time :** Total order cycle time is the average time it takes for an order to be shipped, beginning with the moment the customer places the order. This includes all of the processes in between: accepting the order, selecting the necessary items, packing them, and getting them ready to ship. The shorter this time, the more satisfied the customer.

- **Order lead time :** The average time it takes for an order to reach the customer after it has been purchased is referred to as the order lead time. As with total order cycle time, the warehouse should strive to keep this KPI as short as possible.

- **Backorder rate :** Backorder rates compare the number of backorders to the total number of orders. A high backorder rate indicates that forecasting, planning, and inventory tracking within the warehouse need to be improved.
  Formula: Total backorders / Total orders

- **Fulfillment accuracy rate :** From the total number of customer orders received, this KPI calculates the number of orders that have been successfully fulfilled from start to finish. This includes orders that were delivered correctly, on time, and with the correct products. If this rate is low, the order management process should be reviewed and revised.
  Formula: Orders completed without issues / Total orders received

- **On-time shipping rate:** This metric assesses the efficiency of the shipping process. To avoid customer dissatisfaction, it is critical to maintain a high on-time shipping rate.
  Formula: (Number of orders that have been shipped on time or in advance)/(Total number of orders shipped)

- **Cost per order :** This KPI indicates how much it costs to fulfill one of the customer orders, from the moment the order is placed to the time it reaches the customer. Cost per order can be derived by dividing the total expenses spent on order fulfillment, by the total number of customer orders received.
  Formula: (Total Fulfillment costs)/(Total number of orders)

- **Rate of returns :** The rate of returns reflects the percentage of customers who have returned their items, whether due to factors within the warehouse's control (for example, damaged products, incorrect item sent, or late delivery) or factors outside the warehouse's control and responsibility (such as fraud or problems with the product after delivery).
  Formula: (Items returns/items sold)*100

SAFETY KPIs

The majority of large warehouses operate with large equipment. While these machines are useful, they are not without risks. It is best to keep an eye on KPIs related to warehouse accidents in order to help prevent them in the future. (Inventory,2021)

- **Accidents per year :** This KPI measures how many notable accidents cost time and money during the course of a year. Ideally, all warehouses should and must strive for zero accidents per year, but in the event that this is not the case, this KPI is the best way to keep track of the safety indicators.
- **Time since last accident :** This indicator indicates how long it has been since the last accident.

Conclusion

All of these KPIs and indicators are tools and parameters that assist the management team in studying productivity and material flow within the warehouse. Each KPI has its own set of data, measurement methods, and roles. Most warehouse management KPIs are applicable to most warehouses, even if the warehouses do operate differently.

In projects aimed at incorporating technological advances into warehousing operations in general, and hospital warehousing in particular, the effects are identified, studied, and evaluated using KPI values.

See chapter4.4 the effects of implementing the technological advancements in St.Olavs logistics center

3.3.2 Benefits and positive impacts:

The warehouse's performance, as stated in the preceding paragraph of this chapter, can be studied through the KPIs and their variation and progression. As a result, technological advancements' effects and benefits will have a direct impact on these factors. Some may improve, while others may have erratic performance. This is determined by the nature of the KPI and the evaluation criteria established by the warehouse's management team.

The proper application of technological advancements can have a positive impact on tasks that touch every aspect of the warehousing operations : picking, packing, shipping, replenishment, returns, receiving, sorting, put away

Figure 14: warehousing operations

Improved efficiency and productivity: By automating tasks, optimizing processes, and enabling real-time tracking and monitoring, technology integration in warehousing operations can improve efficiency and productivity. According to MHL-

News, warehouse automation technologies can increase productivity by 30-50% while lowering operating costs by 20-30%. (MHLNEWS, 2014)

Improved inventory management: Technological advancements allow for accurate, real-time inventory tracking, reducing errors and stockouts. According to a Zebra Technologies report, 74% of businesses that implemented real-time location systems (RTLS) saw an increase in inventory accuracy. (Warehousing, 2020)

Streamlined order fulfillment: Automation technologies such as robotics, conveyor systems, and voice picking solutions can streamline order fulfillment processes, reducing picking errors and increasing customer satisfaction. According to an Intermec study, voice-directed picking systems reduced errors by 67% while increasing productivity by 35%. (Intermec, 2005)

Increased accuracy and reduced errors: Barcode scanning, RFID, and vision systems improve accuracy and minimize errors in picking and packing tasks. A study published in the International Journal of Production Economics found that implementing RFID technology in warehouses reduced picking errors by up to 92%. (M.Karkkainen, T.Ala-Risku , J.Holmstrom , 2002)

Faster order processing and delivery: Advanced technologies enable faster order processing, sorting, and shipment preparation, resulting in shorter order cycle times. According to a Honeywell Intelligrated white paper, automated systems cut fulfillment times by 20-40%. (M.Karkkainen, T.Ala-Risku , J.Holmstrom , 2002)

Improved workplace safety and conditions: Automation technologies reduce the need for manual handling of heavy or repetitive tasks, resulting in fewer workplace injuries and better ergonomics. According to a study conducted by the European Agency for Safety and Health at Work, automation has a positive impact on reducing physical workloads and risks. (European Agency for Safety and Health at Work, 2010)

Data driven decision making: Technological advancements allow for greater access to data analytic and insights, allowing for more informed decision-making and process optimization. According to a McKinsey and Company study, data analytic are critical for improving warehouse efficiency and optimizing inventory management. ("Bausch, C., et al." ,2016)

To sum up, Key benefits of the implementation of technological advancements into the implementation of technological advancement into the warehousing operations

(Hairobotics,2022) can be listed as the following :

- **1. Reduced Error Rate**
- **2. Improved Employee Efficiency**
- **3. Increased Warehouse Productivity**
- **4. Reduced Processing time**
- **5. Maximized Space utilization**
- **6. Safe and reliable Operations**
- **7. Improved Inventory Management**
- **8. Reduced operational costs**
- **9. Strengthen Customer Satisfaction**
- **10. Long-term sustainability**
- **11. Fast Scale-Up**
- **12. Higher Resilience**

3.3.3 Downside and negative impacts:

With the advent of technological advancements, the warehousing industry has undergone significant changes in the last few decades. While these advances have provided numerous benefits, they have also had some negative impacts and downsides on the warehousing operations. In this paragraph, the negative effects of technological advancement on warehousing operations are investigated in the literature.

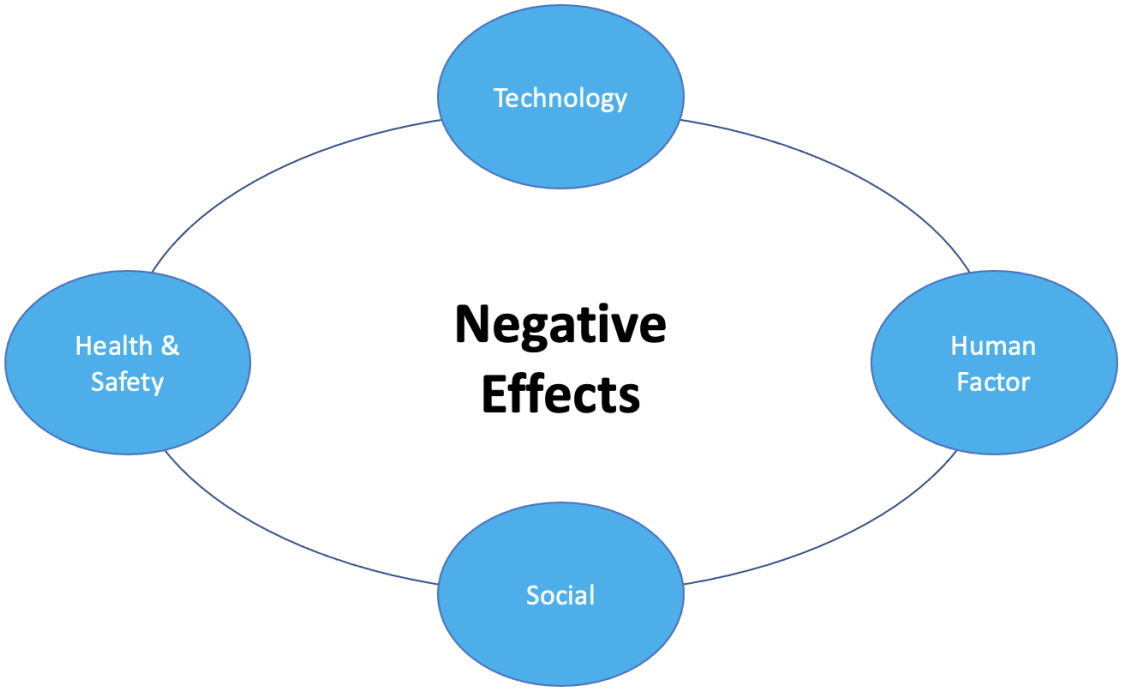

Figure 15: Negative effects factors

Displacement of human workers

The displacement of human workers is one of the most significant negative effects of technological advancements on warehousing operations. Automation and robotics implementation in warehouses has increased in recent years. As a result, manual labor has given the way to automated systems that require less human intervention. Workers who are unable to adapt to new technology may lose their jobs as a result of this displacement. This can be especially difficult for workers who have spent years in the industry and have a thorough understanding of the operational processes.

Furthermore, the use of automation and robotics in the warehouse can result in worker deskilling. Workers may be required to perform tasks that require less skills and manual knowledge as warehouses become more automated. This can be de-

motivating for employees who believe their jobs have been devalued. Furthermore, worker deskilling can result in the loss of valuable knowledge and experience, which can have an impact on the warehouse's overall performance. (D.Koster, R.Le-Duc, 2007)

Increased downtime and system failures

Another disadvantage of technological advancements in warehousing operations is the possibility of increased downtime and system failures. The risk of system failures and downtime increases as warehouses become more reliant on technology. This has the potential to have a significant impact on both productivity and customer satisfaction. Furthermore, the cost of repairing or replacing damaged technology can be prohibitively expensive. The use of technology in warehousing operations can also result in higher costs. While the initial cost of technology may be high, there may be ongoing costs for maintenance and repairs. Furthermore, because technology is constantly evolving, warehouses may need to invest in new technology to stay competitive. Smaller warehouses may not have the resources to invest in new technology, so this can be a significant financial burden.(L.Koste, E.Malizia, 2017)

Negative impacts on the employee health and safety

Advances in technology can also have a negative impact on employee health and safety. Workers may be exposed to new hazards as warehouses become more automated, such as the risk of being struck by automated machinery. Furthermore, the implementation of new technology may necessitate workers standing or sitting for extended periods of time, which can lead to musculoskeletal disorders. Furthermore, as a result of the pressure to adapt to new technology, workers may experience mental health issues such as stress and anxiety. (S.Lodi , R.Hewett, J.Gualandris, F.D'Amico, 2019)

The Impact on the culture and social structure of the warehouse

Finally, technological advancements can have an impact on the warehouse's overall culture and social structure. The relationship between workers and management team may change as automation and robotics become more common. Workers may feel disconnected from their work and that their contributions are undervalued. Furthermore, warehouse culture may become more focused on technology rather than the human aspects of the job. (H.Rau, C.Linder, 2015)

To summarize, while technological advancements have provided numerous benefits to the warehousing industry, they have also had negative consequences. These negative effects include the displacement of human workers, worker deskilling, increased downtime and system failures, increased costs, negative impacts on employee health and safety, and negative impacts on the warehouse's culture and social structure. As warehouses adopt new technology, it is critical to consider these negative consequences and work to mitigate them. By doing so, we can ensure that the benefits of technological advancements are realized without jeopardizing worker safety or warehouse performance.

3.3.4 Conclusion:

While both improved service and lower costs are important reasons for companies to implement warehouse technological advancements, it is discovered that the primary reason is the need to accommodate growth. Business acquisitions, inventory consolidation, product line proliferation, and the increased safety stock associated with lengthy global supply chains are all factors that may lead to an increased scale of operation. In such cases, the literature suggests that the implementation of technological advancements is a viable option for achieving the required throughput at high levels of speed and accuracy while keeping costs to a manageable level. The inclusion of growth as another major reason for automation expands on the understanding established by Dadzie and Johnston. (K.Dadzie C.Dadzie J. Johnston E.Winston, H.Wang , 2022)

The large number of steps involved in technological advancements projects reflects their inherent complexity, but the process that has evolved appears to be fairly successful in keeping projects on time and within budget. However, there is a real risk of a "service level dip," which must be addressed during the planning process. Although most automation projects have formal planning processes in place, these appear to be focused primarily on the installation of new equipment rather than the management of the ongoing operation.

Warehouse technological advancements implementation frequently involves long projects (averaging 20 months) and lengthy build-up periods (averaging 3 months). Automation and "technological advancements", rather than being a short-term market response, must therefore be part of a long-term plan. This implies that warehouses must know their overall volumes for the facility, as well as the likely product and order profiles, with some certainty. Flexibility must then be built into the design so that the automated equipment can respond positively to changes in market requirements. This implies that, rather than basing the project on "the business plan", scenario planning should be incorporated into the design process as described by (Sodhi, 2003).

What we can conclude from this paragraph about the difficulties associated with "technological advancement" implementation processes are:

- Technological advancement projects are frequently motivated by the need to achieve business growth, which appears to be specifically to gain the supply chain benefits of inventory centralisation while keeping costs in the resulting

large distribution centers at acceptable levels in the literature studied.

- Projects involving technological advancements may involve flexibility risks; thus, scenario planning involving such principles and demand chain management must be undertaken at the business requirements stage.
- Projects involving technological advancements do involve service level risks, which must be fully addressed in the planning phase for the management of the ongoing operation, as well as in the time allowed for "snagging" the automated equipment. Realistic time frames appear to be an important prerequisite for avoiding any dips or drops in service level.

3.4 Best practices and common pitfalls to avoid during the implementation process

The project management team for technological advancement is playing a high-stakes game. The goal of the project is to upgrade the warehousing operations. The rewards for success are enormous, while the consequences for failure are dire. These are the main traps of a digital transformation, according to A.Arora, P.Dahlstrom, P.Groover, and F.Wunderlich, as well as the best practices for overcoming and avoiding them (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017) :

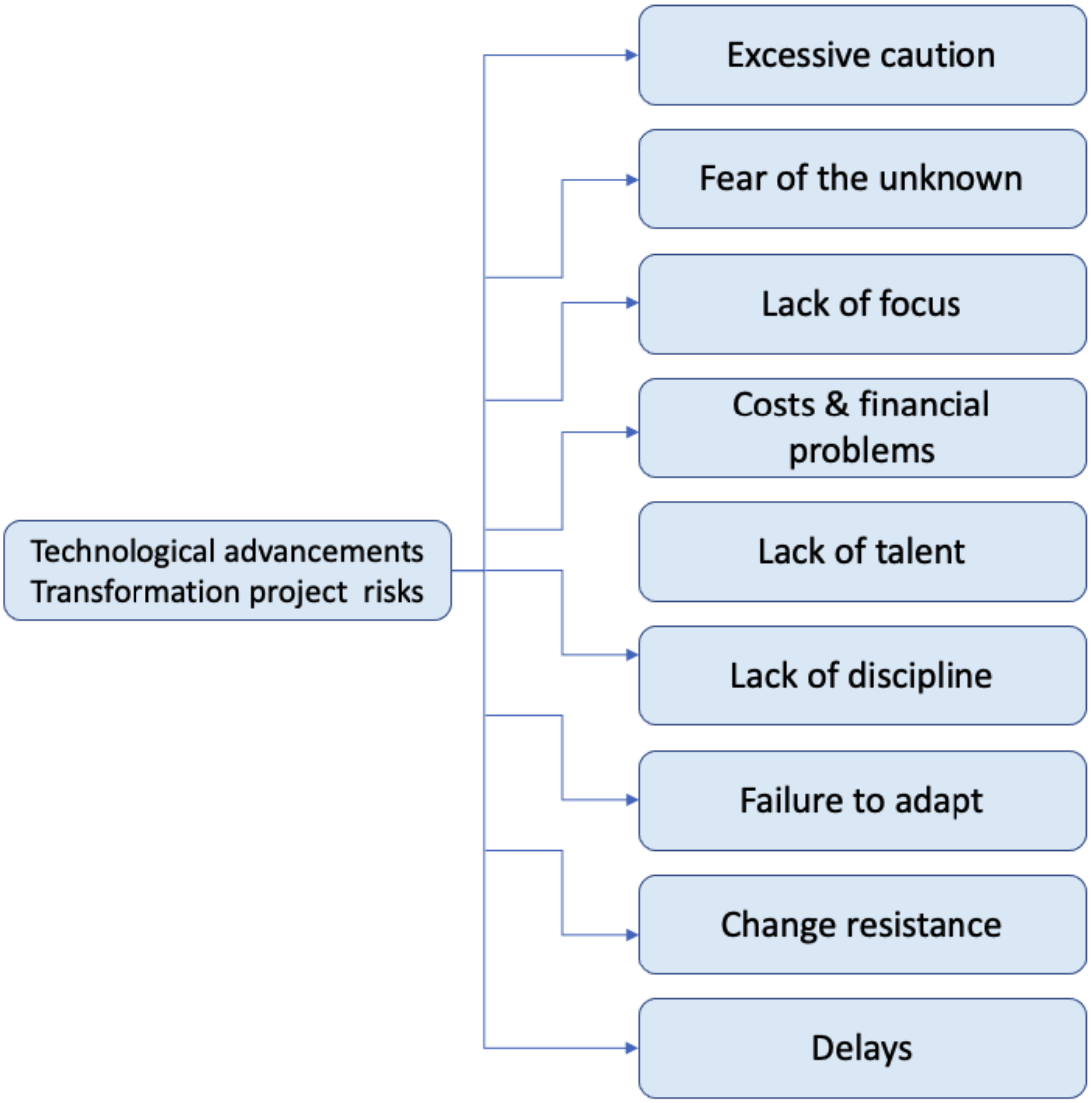

Figure 16: The common challenges of the technological advancements projects management

- **Excessive Caution :**

  According to recent McKinsey research, the most successful companies pursue strong and disruptive strategies (J.Bughin, L.LaBerge, A.Mellbye, 2017). They place large bets on new technologies and business models, promote a test-and-learn culture in which every failure is an opportunity to improve, and launch change initiatives that transform their entire organization. However, taking on more risk does not imply being more risky. Making rash decisions, disregarding common sense, and losing sight of where the value is can derail bold initiatives.

- **Fear of the unknown :** The best companies begin by determining where value is created and destroyed,(A.Dawson M.Hirt J.Scanlan 2016) and they do not limit their analysis to their own industry or competitors. This external analysis should be accompanied by a thorough internal evaluation. This begins with a thorough assessment of a warehouse assets—brands, capital, data, customers, products, and people as well as capability gaps. The best businesses then create an objective picture of their digital quotient, the elements of their business that add the most value, and the structural disadvantages they face.

  Dispelling the unknown also includes painting a compelling picture of what the future could look like for the entire Warehouse. Experimenting with hackathons and war gaming aids not only in the development of innovative new operations handling models, but also in making them more tangible so that leadership can align around them.

  This extends to the overused term "technological advancement implementation," which is frequently misunderstood by leaders and employees alike. Leaders can address this by thoroughly defining and explaining what the technological advancement implementation truly entails, such as improving customer experience to become the number-one service in the category or dramatically increasing supply chain productivity. (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017)

- **Lack of focus :**

  It is also critical to concentrate on the right kinds of initiatives. Too often, managing team invest in programs that produce short-term gains but cannot be scaled, are not sustainable, and add no value. To avoid wasting energy, any technological advancement project should begin by understanding customer needs and developing solutions that not only address them but also have the potential to have the greatest impact. (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017)

- **Costs and financial criteria :**

  Some technological advancements implementation projects fail because costs skyrocket while savings or revenue growth take longer than anticipated. Leading the transformation project begin by focusing on quick wins to unlock value so that the effort can pay for itself, usually within the first three months. In fact, the most successful companies generate more savings or revenues than are required to fund a transformation.

  Savings and revenue can often be banked by utilizing existing tools and data, as well as a willingness to do things differently. These opportunities are frequently identified as early as a week into a project. A good place to start is by evaluating the customer decision journey. In consumer sectors such as banking and telecommunications, the joining and on boarding processes for new customers frequently provide numerous opportunities for significant improvement. (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017)

- **Talents and skills:**

  Any effective talent search should begin with identifying the issues that must be addressed. This clarifies the skill sets required. Following a preliminary analysis, one company determined that 11 people with specific skill sets —"leaders" and "doers"— were required to complete a core project as part of a transformation. It found the right people at a leading technology firm and paid a full-fledged premium to hire them. Because they were eager to work with the first hires, the next 50 people came at only a 20% premium later in the transformation. The team generated $1.4 billion in incremental annualized revenues in less than nine months, a massive payoff for what appeared to be a disproportionate investment.

  Creating a start-up-like working environment with informal spaces for people to gather and share ideas can aid in attracting top talent. Creating a system for integrating these outside hires is also critical. We've seen some large corporations hire a large number of digital talent, place them in a start-up environment, and then essentially forget about them. If left to their own devices, new employees will begin working on their own projects rather than yours.

  (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017)

- **Lack of discipline (Respect of schedule):**

  Many managers of the implementation of new technologies projects do prioritize output-based KPIs such as EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization) growth, digital revenues as a percentage of total revenues, or capex (Capital expenditure) reduction. However, such broad

metrics do not isolate the factors that contribute to a particular result. It's more efficient to create a set of simple input metrics that track elements like SEO (Search Engine Optimization) conversion and app traffic, while clearly defining who owns each item and is accountable for the outcome.

Investing like a venture capital firm is another way to instill discipline. Hold frequent check-ins with explicit expectations and clear governance; withhold the next tranche of funding until the project meets milestones or KPIs; and be strict in eliminating the under performing efforts. The successful projects have simple governance, escalation, and response procedures in place, as well as mechanisms to allow for course correction when experiments fail (which many do).

Discipline is not the same as rigidity. A flexible resourcing model is required to move people and funds, for example, to promising developments and address key issues quickly and in an efficient way.

- **Failure to learn :**

  A study that was conducted by Google, showed that when employees (operators or managers) found they can take risks without being shamed or criticized for failure, they did a better work. (C.Duhigg,2016)

  Effective learning of the new technologies and processes do take time and assistance. The implementation of technological advancements projects managers must invest in systems to capture and learn from lessons. Amazon logistics of instance has invested in systems that are designed to make learning as transparent as possible, with dashboards that show what tests are being run, who is running them, and how customers are responding. (A.Arora, P.Dahlstrom, P.Groover and F.Wunderlich, 2017)

  So, in order to manage the human factor training process, it is critical to value the learning and training period, develop learning prototypes, test and refine them until they reach a minimum level of convenience for the training required. During training, it's critical to keep the information flowing both ways and to always seek feedback in order to make the operators feel included and a part of the warehouse's transition.

- **Change fatigue :**

  Projects involving the implementation of new technologies are typically viewed as a transition from a low to a high tech environment. The project management team frequently musters the resources and energy to carry out a few experiments with novel approaches. However, maintaining the momentum of a major change effort in the face of daily challenges is a challenge of a different order. "Change Fatigue." (J.Meffert A.Swaminathan, 2017)

The sheer scale and complexity of the change and its implementation can overwhelm teams, which in this case includes managers and operators. Small projects with frequent milestones would be an effective way to manage this so that teams feel a sense of accomplishment! Also, keep things simple and clear by limiting the number of warehouse operations KPIs, for example.

project leaders should also address senior-level turnover. This effect undermines continuity and breeds cynicism among on-the-ground workers. While senior-level turnover is unavoidable in most businesses, companies have been able to maintain continuity in their change programs by recruiting influential middle managers as change evangelists. Managers can build continuity at the level of the business where the work gets done by elevating their profiles, giving them real responsibilities, such as leading agile teams, and generously rewarding them for their efforts.

- **Project Timeline: Going too slowly**

  Speed is of the essence when it comes to reacting to the market changes and capturing revenues opportunities. One way to gain speed is to automate time-consuming processes and tasks. For instance, adopting "test driven development" writing automated tests for code before writing the code itself can greatly accelerate development.

  The most effective businesses instill agility as a way of life. They use short development cycles to address specific needs, repeatedly test rudimentary fixes with customers, and produce "good enough" solutions.

3.5 Summary of the literature review:

According to the reviewed literature, a flexible warehouse should increase productivity, improve flexibility and space utilization to accommodate the increase in SKU's (Stock keeping units), have a higher throughput, and deliver faster. As a result, automation is required to achieve these factors. Fixed mechanized and fully automated systems, on the other hand, are incapable of adapting to changes in product mix and market demand. To meet the demands, warehouses and warehousing technology must be adaptable, responding quickly to challenges such as continued growth in omni-channel fulfillment, new competitive threats, shorter delivery cycles, or unexpected technological advances. A flexible automated warehouse must employ automation solutions that are simple to deploy and modular, as well as include the embedded intelligence required to capitalize on machine learning and other advancements.

According to the literature review, the hospital warehouse must meet the following criteria: a high level of service; accuracy in picking and inventory; and performance of the production units. The performance of the hospital warehouse will be positively impacted by the selection of the appropriate technologies, as discussed in this chapter, leading to better operations.

According to the reviewed literature also, the combination of technological advancements, data collection , and management solutions is critical to achieving a flexible warehousing operations. This system must be able to collect data, improve operational visibility, improve system coordination and communication, and adapt to changes in real time.

Construct	Element
Automated equipment	• Automated storage: AS/RS, AS/RR mini-loads, carousels, and vertical lifts • Robotics: Palletizing, picking, or packing solutions • Transportation: Conveyor system and automatic guided vehicles (AGV's)
DATA collection technologies	• Labelling technologies: barcode scanners and RFID scanners • Picking technologies: pick-by-light, pick-by-voice and put-to-light
Management Solutions	• Software solutions: WMS, WCS, and WES • Routing of AGV's and conveyors • Picking optimization • Simulation solutions

Table 2: A framework of a flexible automated warehouse

Table 2 depicts the technologies discovered in the literature review that should improve flexibility in an automated process in a warehouse in order to increase productivity and efficiency and to keep up with the service level requirements. The review demonstrates that the use of technological advancements cannot define a flexible automated warehouse. As a result, the mentioned technologies must be combined to represent a flexible automated warehouse.

The literature review also identifies the major challenges associated with the implementation of technological advancement into the warehousing operations. The challenges are divided into three categories: "Project management" in the three main phases (before, during, and after), "technological challenges" such as flexibility, cost, and security, and "human related" such as resistance to change, safety and health risks, and cultural behaviors.

The literature chapter emphasizes that the effects can be identified and studied based on the key performance indicators in their various and different shapes and types depending on the warehouse specifications and the objectives of the project of implementing technologies. As good and positive and beneficial as the effects of technological advancements are (improved efficiency and productivity, inventory management, order fulfillment, accuracy, order processing, safety...), it is important to keep in mind the downsides and negative effects and target averting them from the beginning of the projects (displacement of human workers, increased downtime and system failures, and negative impacts on employee safety and working culture).

The theory also revealed a number of traps and common errors to avoid and predict before embarking on such projects. Excessive caution, fear of the unknown, lack of focus, costs and financial problems, a lack of talents and discipline, a failure to adapt, resistance to change, and delays are all examples of risk factors. To reduce the risks associated with this type of project, the project management team must be aware of these traps and risks.

The majority of the literature was related to the general warehousing operations and the implementation of technological advancements in a broad and general sense. The following chapter will delve into the operations of medical warehousing and investigate the validity of the theory stated in the hospital warehouse.

4 Case study

This chapter presents the case study that support this research paper and its findings. The empirical information and data gathered during this study are the result of company visits, interviews, and collaboration with warehouse managers, operators, and technical teams. The main goal of this chapter is to answer the project's research questions and narrow the study's scope to the hospital warehouses.

The chapter begins by introducing the industrial partner of this case and the project under investigation. The following section delves into researching and identifying the specifications of the warehousing operations in the medical field. Afterwards, the case study delves into investigating the challenges and effects of implementing technological advancements into the hospital warehousing operations. A summary at the end lists the findings of the case study and opens the door to the discussion chapter.

4.1 Introduction to the study case:

4.1.1 The case company

The study case backing up this research paper is related to the warehouse of St.Olavs Hospital in Trondheim.
St. Olav's University Hospital (in Norwegian: St. Olavs Hospital Universitetssykehuset i Trondheim) is the hospital of the city of Trondheim (Norway) located at Øya. State owned infrastructure, the hospital cooperates closely with the Norwegian University of Science and Technology in research and in education of medical doctors.

St. Olavs hospital has several regional and national tasks for the 725,600 inhabitants of Møre, Romsdal and Trøndelag (January, 1st 2018). (stolav,2022)
Such big hospital needs to have a very large amount of stocks that can satisfy the high demand regarding medical products.
The warehouse associated with St. Olavs Hospital, also known as the logistics center, is owned by Health Midt-Norge (the state office or organization in charge of the health case system in the middle of Norway).

Helse midt norge and the local authorities felt the need to upgrade the logistics

operation of the region's health care system in 2004, for a variety of reasons:

- Increasing demand
- Increasing challenging circumstances
- Concerns about the warehouse's performance and service quality
- Picking and accuracy issues appear to be costing both the warehouse and the hospital a lot of money.
- The manual methods of material handling has a negative impact on supply and demand operations.

As a cost-cutting measure, and with the primary goal of providing a better, more accurate, and solid service level in the health care system, Helse midt-Norge decided to invest in the construction of a new logistics center or warehouse equipped with cutting-edge technological advancements. Providing better service to the region's hospitals and meeting the growing demand in the medical field in Trøndelag, not only from the large hospitals like St.Olavs in Trondheim, but also from the region's small, regional, and private hospitals and clinics.

4.1.2 The four main phases of the project :

The study case project was implemented in stages. According to the logistics center's operations manager, the project's implementation timeline is divided into four major phases:

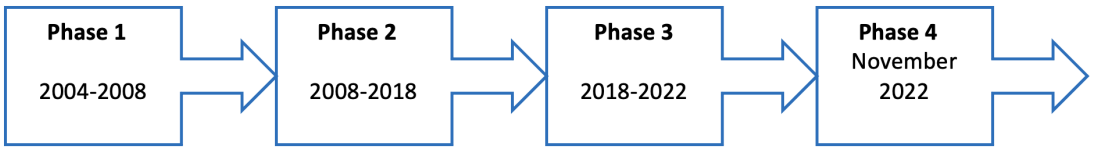

Figure 17: The four main phases of the project

- Phase 1: (2004-2008) The decision to build a new logistics center with cutting-edge technology in order to provide better service to the region's hospital and meet the growing demand in the medical field in Trøndelag.

- Phase 2: (2008-2018) Preparing the project outline and the practicalities of building the new logistics center (location, size, capacity, etc.) During this time, a regional logistics system (SAP) was implemented in order to have a standardized platform for the region's warehouses and hospitals logistics.
- Phase 3: (2018-2022) The project group was formed, technologies were chosen, suppliers were selected, and constructions started.
- Phase 4: (November 2022) Opening of the new logistics center.

4.1.3 The timeline of the study case :

The master thesis project began in late phase 3 of the project of implementing technological advancements, more specifically in the period of moving from the low to the high tech warehouse. The study lasted until an advanced stages of the phase 4.

To investigate the effects, data and information were collected from both the old warehouse (timeline: October - November 2022), and the new logistics center (new high tech warehouse) immediately after the opening (Time line: November-Mai 2023).

	September	October	November	December	January	February	March	April
Old warehouse								
New warehouse								
Initialization	*Determine the characteristics of the hospital warehouse*							
RQ1			*The challenges of the implementation*					
RQ2					*The effects of the technological advancements*			
RQ3	*Building the framework of implementing technological advancements in the hospital warehouse*							

Figure 18: The timeline of the study case data collection

- Initialization: Because it is critical to begin with, the identification of the characteristics and specifications of the hospital warehousing operation did occur early in the project. As a result, the identification of those characteristics was based on the old warehouse and the analysis of the information and data from it.
- RQ1 : The implementation challenges were investigated during the transition period, which began in November. (Figure 18)

- RQ2 : The effects were studied and identified by comparing the new warehouse's performance to that of the old warehouse. (January-April) (Figure 18)
- RQ3 : Building the framework for implementing technological advancements into the hospital warehouse is the goal that ties all of the previous points together. This is why it has been ongoing throughout the entire project (September-April). (Figure 18)

4.2 Operations management in the hospital warehouse

4.2.1 Layout and material flow:

The Logistics center of the hospital under study adheres to the traditional main departments and structures of the general warehousing operations. A receiving area where trucks arriving from suppliers deliver orders in specialized containers. Once inside the warehouse, the products are removed from their containers and placed in the most appropriate and convenient location in the stocking area. However,there are numerous material handling conditions that arise due to the nature of the products in the medical field.

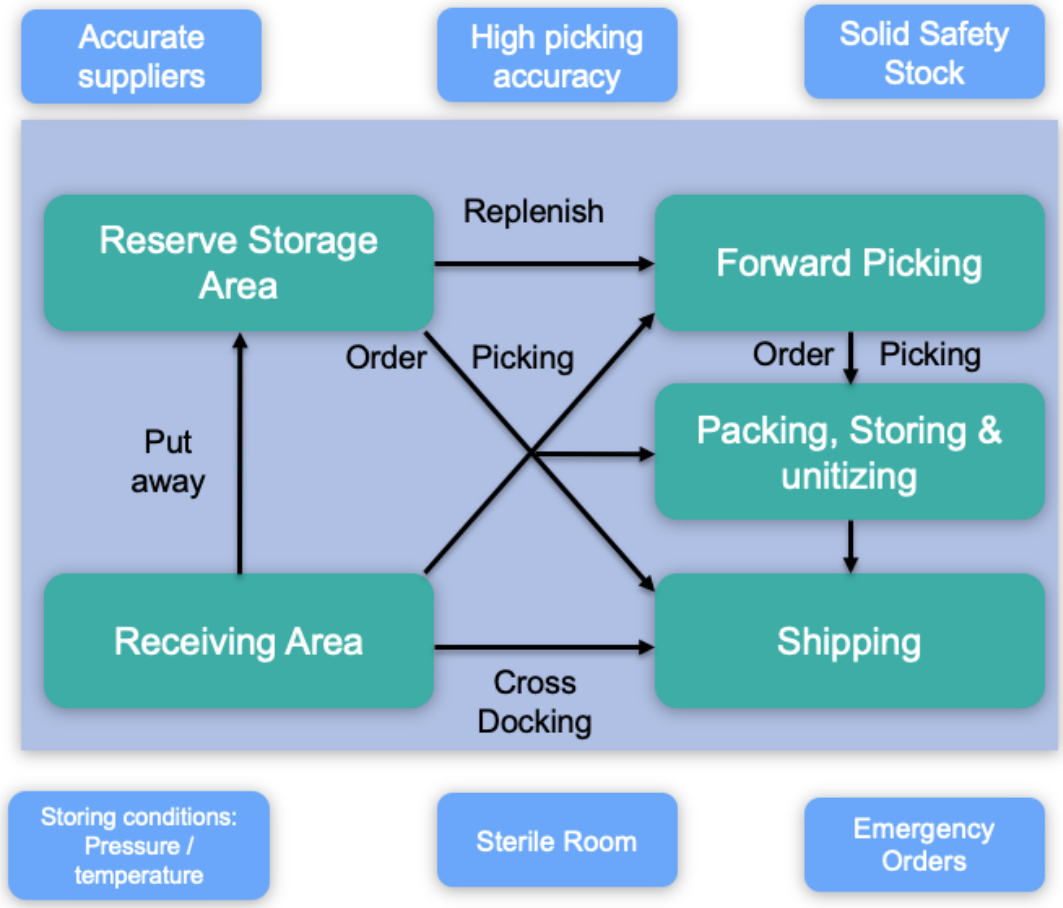

Figure 19: Material Flow

When a product needs to be shipped to a customer, the picking team receives the picking order and places the items in the containers that will be shipped later that day.

In terms of handling criteria, medical products have a wide range of conditions, and handling those parameters is no laughing matter since they have a direct impact on people's lives. A small uncertainty means and implies that the entire stock is to be thrown away.

First parameter is **"Temperature"** : Many products must be stored at some specific temperatures, which are typically lower than the ambient temperature in regular warehouse storage areas. As a result, the first condition for the hospital warehouse's storing area is the presence of a "Cold Room."

The second factor that the medical products can impose is the **"The Pressure"** : In terms of infrastructure investments, such parameter is extremely demanding. A room with a high pressure is required in the warehouse hospital for unpacking the various sterile products. This technology of high pressure pushes all the bacteria and the unwanted dust outside of the storing room, preserving the quality of the products.

Fire Zone : A high range of medical products do require a high level of sterilization, and the vast majority of solutions and liquids that can be used for sterilization are dangerously flammable. An enormous risk that jeopardizes not only the building's integrity but also the lives of those who work in it. This is why the hospital warehouse, such as the one of St.Olavs hospital, is equipped with a room "anti fire" with a high technology allowing the walls to prevent the expansion of the fire and any risks of explosion to the other sides of the warehouse.

All containers used for products handling, transporting inside the warehouse, and shipping from and to St.Olavs hospital, are disinfected and sterilized on a regular basis as part of the conditions regarding the safety and sterility of the material flow process inside the warehouse. A large washing machine handles this process in the warehouse, and a color code indicates whether the container is clean and ready to use, or if it is out of service until it is cleaned.

So, in addition to the regular structure of the normal warehouses, the material handling conditions are different and do require higher amount of investment and precautions when it comes to the medical warehousing infrastructure.

On the other hand, the logistics center's management team confirms that, in terms of warehouse regulations and commitments, it is critical to have a very high service level from suppliers. The suppliers, as well as the warehouse and the hospital depart-

ments, must meet strict accuracy standards. The safety stock is another important factor that is highlighted for medical operations. In the following paragraph, while evaluating the KPIs, more detailed information about operations management in the hospital warehouse is presented .

4.2.2 The hospital warehouse relevant Key performance indicators:

As we discussed in Chapter 3.2.1 (Warehousing Operations Performance Indicators KPIs), there are numerous KPIs that can be used to evaluate warehouse performance and determine whether or not processes are efficient enough. These KPIs aid in identifying what is lacking and what needs to be done better and more efficiently. In addition, the study of the effects of technological advancement in our research paper should go through the relevant KPIs that would give the best and most relevant description of the impact of the new processes on the operations. As a result, in this section, we will attempt to identify, measure, and explain the relevant KPIs for the medical warehousing operations.

The KPIs for this section of the case study were calculated using data and information from the old warehouse. This is due to the project's timeline and also because the goal at this stage is to determine the relevant KPIs to the medical field rather than investigate the effects or challenges of technological advancements.

Inventory KPIs :

- **Inventory deviation :**

  In St.Olav hospital warehouse, the inventory manual counting is done three times a year, usually during Mai, September and December. During these three periods, the warehouse managing team keeps truck and register on the internal system all the products in and out to keep the accuracy as high as possible between what is registered and what is found after the big manual inventory. The coming graph shows the evolution of the inventory accuracy of the warehouse in the period between 2018 and 2021.

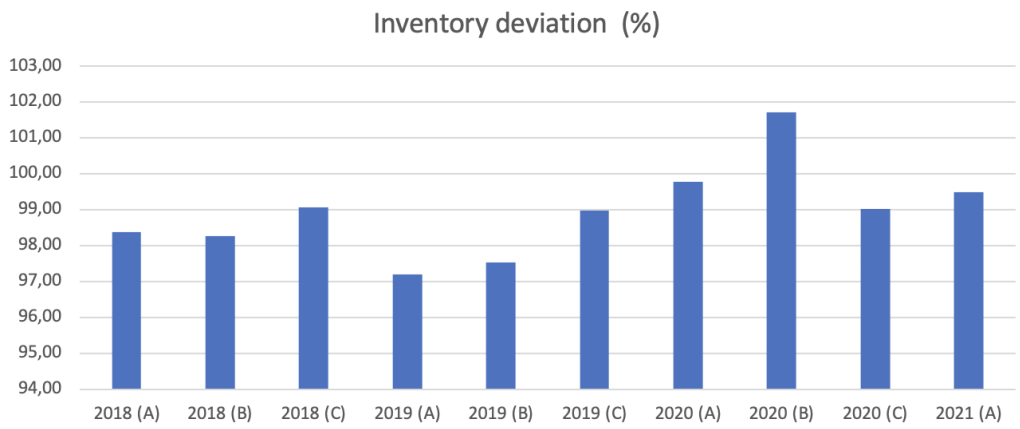

Figure 20: Inventory deviation of the hospital warehouse

On the period studied, the warehouse inventory accuracy varies between 97% and 99,7% except the second third of 2020, where the accuracy was beyond 100% and reached the 102% . An exception that occurs frequently, according to the warehouse manager, and it is due to the handling of returns and how they are operated in the warehouse. After receiving the order, clients or hospital departments usually have the option to refuse it and send it back for one of the following reasons: wrong items packed, the item is damaged, the hospital ordered the wrong item, or the client simply no longer wants this product.

Many of these products are sent at random because there is no set deadline or time frame for returning the items to the warehouse. As a result, many products are sometimes returned after being sent for days or weeks. Once returned, these products are handled manually and either discarded or returned to the warehouse storage if the condition of the products is seemed acceptable. And many of these products are not typically pinged and registered as new in the warehouse stock or SAP system. Due to poor return management and lack of process organization on the both sides: the warehouse and the hospital departments, the warehouse has practically more than what is registered on the system over time. This KPI is then crucial to remember and identify for St.Olavs warehouse.

- **Carrying cost of inventory :** This factor is irrelevant, and, more specifically, is not permitted by legal laws and regulations for hospital warehouses, at least in Norway and the EU. It is important and necessary to keep some products in stock at all times, regardless of the carrying cost of the storage inventory... Some of the products are rarely or never sold, but the warehouse should keep them on hand in case of emergency. These stocks are used to back up in pandemic situations, such as Covid 19, when the st.Olavs hospital warehouse stock of Antibac and sanitary gel was in short supply for the first time in years,

despite the fact that it was always in excess and kept only in stock in case of need.
So the hospital warehouses doesn't take into consideration the carrying cost.

- **Inventory turnover:** The inventory turnover measured for the second quarter of 2022 of the St.olav hospital warehouse is the following:

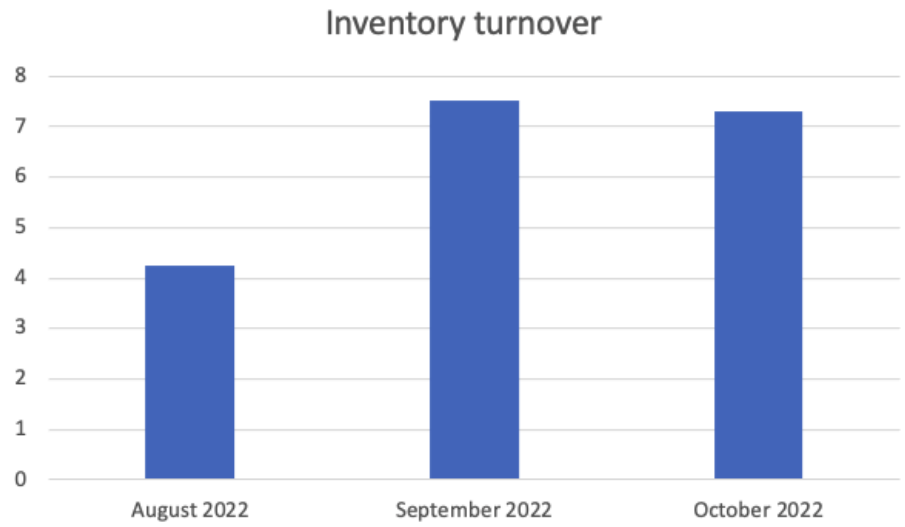

Figure 21: Inventory turnover of the hospital warehouse

A good turnover ratio, is between 5 and 10. (NetSuite,2022) In the case study warehouse, the turnover was very low in August, owing to low demand during the summer because many hospital personnel are on vacation... but starting in September, the KPI returned to the safe zone, reaching 7.5 and 7.3 in September and October, respectively. In this case, the warehouse should focus more on season balancing and better managing this factor during the summer quarter of the year. This KPI is relevant, but not high on the priority list.

Receiving KPIs :

- **Receiving efficiency:** The number of working hours is set by the warehouse and does not vary from day to day. Every shift, 6.5 people work for a total of 7,5 hours per shift, as required by labor law. This results in a monthly working hours average of 975 hours for the warehouse. (Because the data was available for the entire month, it was not possible to study this factor per shift or week.) The statistics of the hospital warehouse :

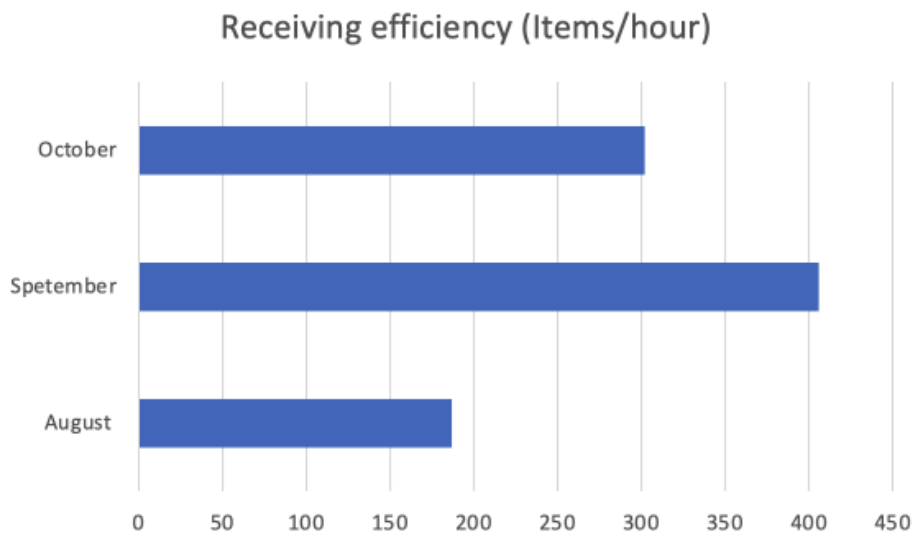

Figure 22: Receiving efficiency of the hospital warehouse

The efficiency varies from shift to shift based on the number of items to be handled by the team. However, this factor fluctuates and changes suddenly, which is a bad sign for the warehouse management. Because of the fixed working hours per shift, the team is either overworked and exhausted or has nothing to do, causing efficiency to drop. It is critical for the warehouse to adjust working hours based on demand and the number of items to be handled. Of course, this requires a good forecasting system and a thorough understanding of the team's capabilities. It is also relevant to mention that the receiving capacity of the team is impacted by the products ordered by the hospital from outside suppliers but shipped through the warehouse. This KPI is then crucial to remember and identify for St.Olavs warehouse.

Putaway KPI :

- **Accuracy Rate :** This put away KPI reflects and calculates the proportion of items that were correctly put away from the first time and were not corrected. There is no direct access to the inventory put away correctly in the study case, but it has been concluded by subtracting the number of corrected items (meaning not put away correctly the first time) from the total amount of products received, and the data scale is per week.

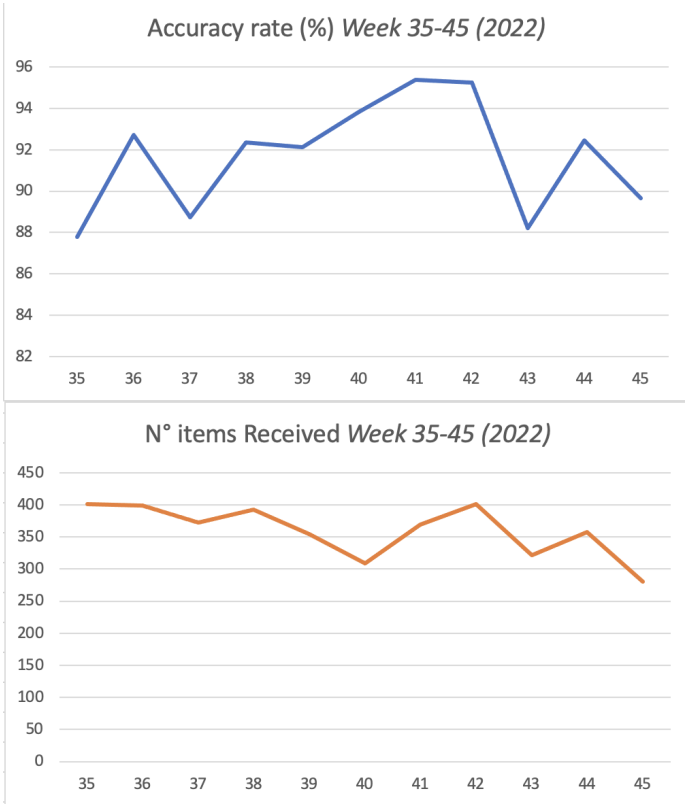

Figure 23: The accuracy rate of the hospital warehouse and the amount of items received per week

The graph clearly shows that the accuracy rate is neither stable nor constant over the weeks and varies from one to the next. However, in theory, the accuracy rate as a putaway KPI should be directly related to the number of items received. The higher the number of items to handle, the lower or constant the accuracy rate. However, by superimposing the two graphs (accuracy rate and number of items), this rule is broken, and some weeks for a very low number of items the accuracy rate remained poor, while in others for a higher amount of work load the accuracy rate reached a peak of good performance.

This can directly reflect the fact that some other factors related to the hospital warehouse have an impact on the accuracy rate, and it is necessary to work more on resolving them and making the accuracy rate more controlled and stable. Thus, monitoring this KPI is of great importance for the hospital warehouse.

Order management :

- **Picking accuracy :**

  This factor shows how accurate the items are being picked from the hospital warehouse to the clients.

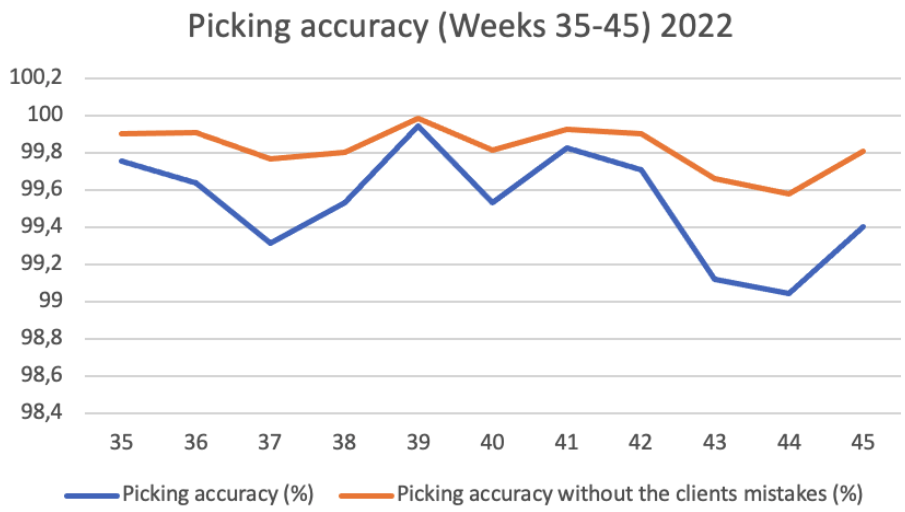

Figure 24: Picking accuracy of the hospital warehouse

Items that are mis-packed for various reasons, such as misplacement in storage, incorrect placement, wrong wagon..., can have a direct impact on the picking accuracy. All of the preceding reasons are associated with the warehouse's internal management and personnel. However, an item can be considered misplaced and have an impact on picking accuracy when it is the client's fault and the order was incorrect from the start. In the figure above, it can be seen that when we ignore the client's mistakes, the picking accuracy increases.
This leads to the conclusion that the hospital warehouse needs to work on improving ordering accuracy as well as client return management, as previously discussed. Aside from that, the majority of incorrectly selected items are the result of misplaced or difficult-to-find products in the warehouse. Also finding and picking the correct item has a direct impact on the picking time. Because of the sensitivity of the medical operation, picking accuracy is very important and is at the top of the list of KPIs to monitor and keep track of.

- **Total Order cycle:** This KPI tracks how long it takes to ship an order, from the time the order is placed until it is shipped. However, in the case of the St.Olav warehouse hospital, the total order cycle time is constant and fixed because the departures, the start of the picking processes, and the truck destinations are all fixed. An order may be received on a given day, but it will

not be treated and processed for picking until the day of the client's shipment. Total Order cycle KPI is not relevant in the case of the hospital warehouse.

Order lead time : For the same reasons stated above it is not relevant to measure since it's constant and fixed by the schedule.

- **Backorder rate:** Backorders are orders for goods or services that cannot be filled at the moment due to a shortage of available supply. The hospital warehouse, by law and regulations, and because it interferes with the public health system's process, must have many backup suppliers in case of need because the products are usually vital and a shortage in stock can have a direct impact on human life. So, in most cases, when a supplier is unable to deliver the required products, the warehouse transfers the order to another supplier who can deliver it as soon as possible. Because the first order will never be delivered, it is placed on an infinite Backorder waiting list according to the warehouse managers. The Backorder KPI is not well managed and the data available within the framework of this study does not allow it to be calculated since the results will be erroneous due to what has just been explained. KPI not relevant.

- **Fulfillment accuracy rate:**

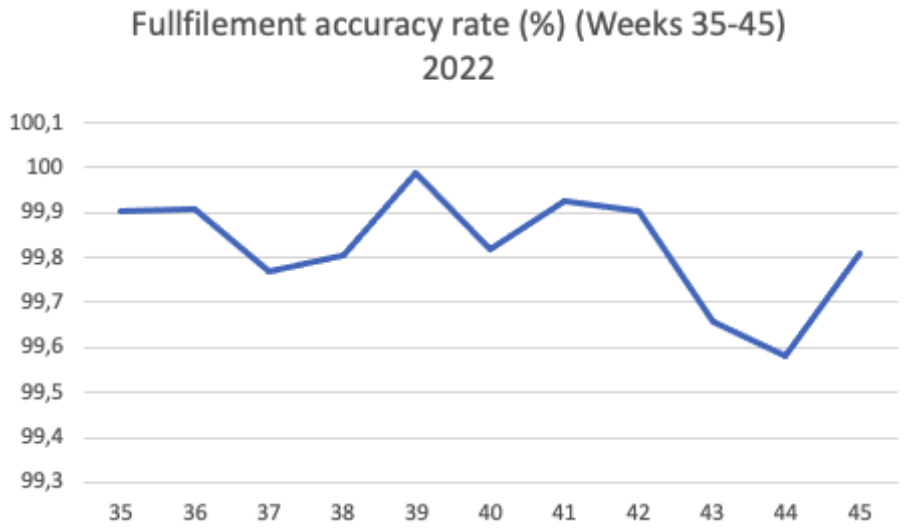

Figure 25: Fulfillment Accuracy Rate of the hospital warehouse

This factor should be as close to 100% as possible, and should not fall below 96%. The fulfillment accuracy in the hospital warehouse remains quite high and well maintained. We can also see that the warehouse reached 99.98% on week 39 of 2022, which is a very high level. So the challenge with this KPI is to keep it as good as it is now, and keep up the good work in terms of fulfillment accuracy.

- **Rate of returns:**

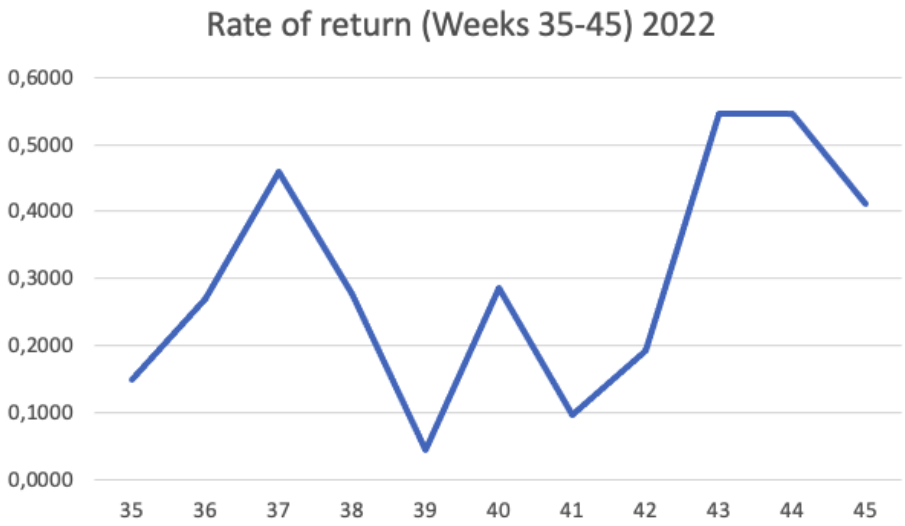

Figure 26: Rate of return of the hospital warehouse

This factor needs to be as close to zero as possible. It reflects the amount of items that were sent back to the hospital warehouse from the client. The reasons behind these returns are quite different and diverse from a warehouse to another regarding the agreement between it and the clients. For the st.Olav hospital warehouse the clients can send back returns if it is in one of the following situation :

- Wrong item picked sent (warehouse mistake)
- Wrong item ordered by the client (Client mistake)
- Item damaged (Supplier mistake or the warehouse)
- The item is no longer needed by the client
- The warehouse does also receive a lot of blank returned items (no reason given)

To all of these factors, st.Olav warehouse does not impose a limit time on the client to return the wrong or unwanted items. so it happens that a lot of returns are sent days or weeks after their initial delivery date. This impacts the operations management, the inventory management and also financially the warehouse is impacted since the clients ask usually for a refund after sending the item back.

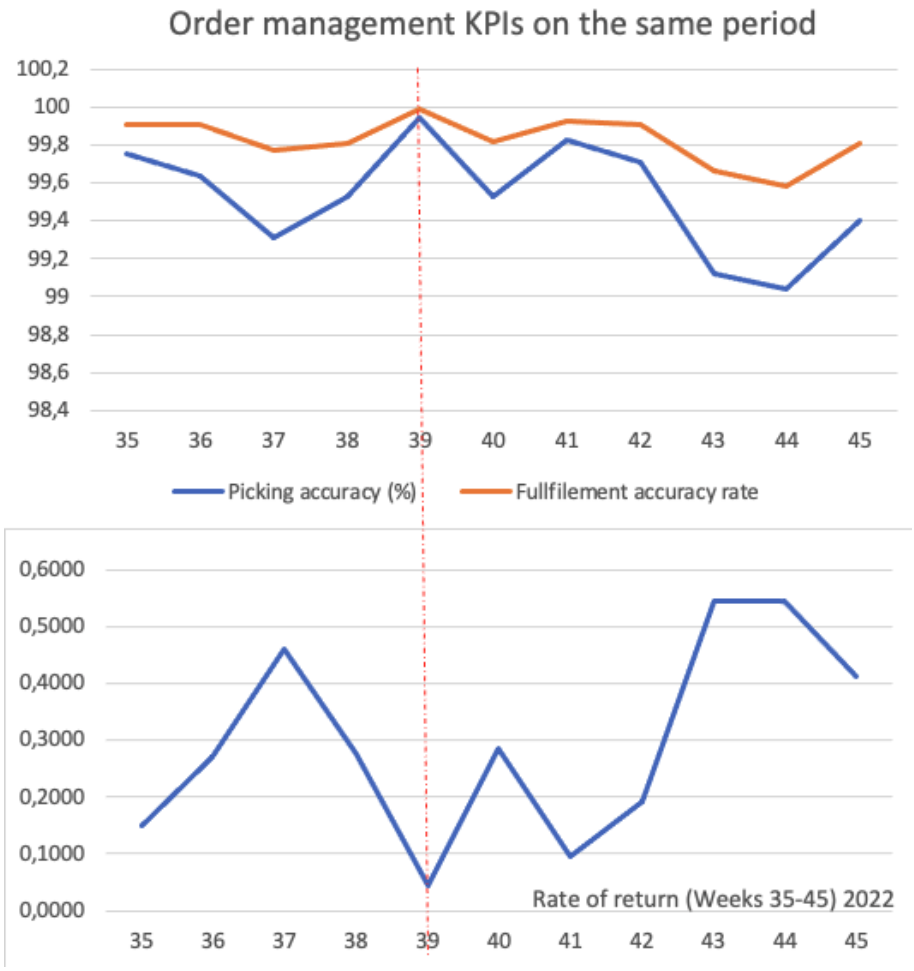

Figure 27: Order management KPIs of the hospital warehouse

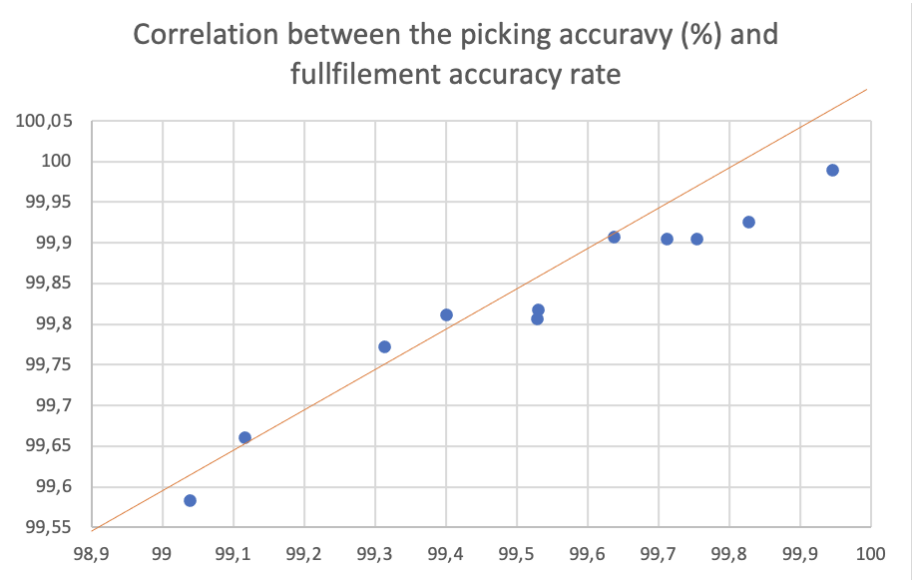

Figure 28: The correlation between the picking accuracy and the fullflement accuracy rate in (%)

It is important to mention that after comparing the two main order management KPIs, we can see that they are correlated to each other and impact directly each other. Indeed, the higher is the picking accuracy the lower is the rate of return , since the amount of correct orders get higher.

SAFETY KPIs :

- **Accident per year:** The warehouse management team places a high value on the safety of its employees. Specific tools and equipment must be worn throughout the warehouse. Every outsider who enters the warehouse must wear specific clothing to avoid bacteria transformation or negatively impacting some sensitive products. The sterile zone is also a very sensitive area, and access to it is strictly limited to those working or visiting. All of these rules and conditions contribute to a very low number of serious accidents each year and a high level of security within the warehouse. According to the St.Olav hospital warehouse operations management team, one accident occurred in 2021 (December, 2021), resulting in a physical damage. During peak season, there is a higher rate of mishaps, which the warehouse tries to manage and reduce as much as possible.

Hospital warehouse relevant KPIs :

Taking the previous analysis into account, it appears that the following are the most important KPIs for st.olavs warehouse:

KPI Group	Key performance indicator	Relevance level for the hospital warehouse	Factors impacting this KPI
Inventory KPIs	Inventory Accuracy	HIGH	WMS + returns handling + Storing planification + Safety stocks
	Shrinkage	HIGH	Damaged items
	Carrying cost of inventory	LOW	
	Inventory turnover	HIGH	Clients + good service level
Receiving KPIs	Receiving efficiency	HIGH	Operators' performance + storing tools + WMS
	Cost of receiving per line	LOW	
	Receiving cycle time	HIGH	Operators' performance + storing tools + WMS
Put away KPIs	Accuracy rate	HIGH	WMS + lean and layout
	Put away cost per line	LOW	
	Put away cycle time	LOW	
Order management KPIs	Picking accuracy	HIGH	WMS + picking tools + lean and layout + Operators performance
	Total order cycle time	LOW	
	Order lead time	LOW	
	Backorder rate	HIGH	Suppliers
	Fulfillment accuracy rate	HIGH	Internal material handling + suppliers
	Cost per order	LOW	
	Rate of returns	HIGH	Clients + picking accuracy
SAFETY KPIs	Accidents per year	HIGH	Work environment
	Time since last accident	HIGH	Work environment

Table 3: Hospital warehouse relevant KPIs

The priority of the KPIs varies from warehouse to warehouse, and we can conclude and confirm that the priority is given to the quality of performance and the efficiency for the case study warehouse, so the KPIs related to these factors are prioritized and are important to keep the operations running at a high level. The safety KPIs are also critical for this type of operations.

4.3 The challenges of the implementation of technological advancements in St.Olavs logistics center:

The study case project was implemented in stages and over time. (Figure 17)

The implementation and leadership of such a high-tech project comes with its own set of challenges and complexities that the project must face and overcome. In this paragraph, we will identify and characterize these challenges using information gathered from warehouse visits, interviews with the managing team for St.Olavs logistcs center.

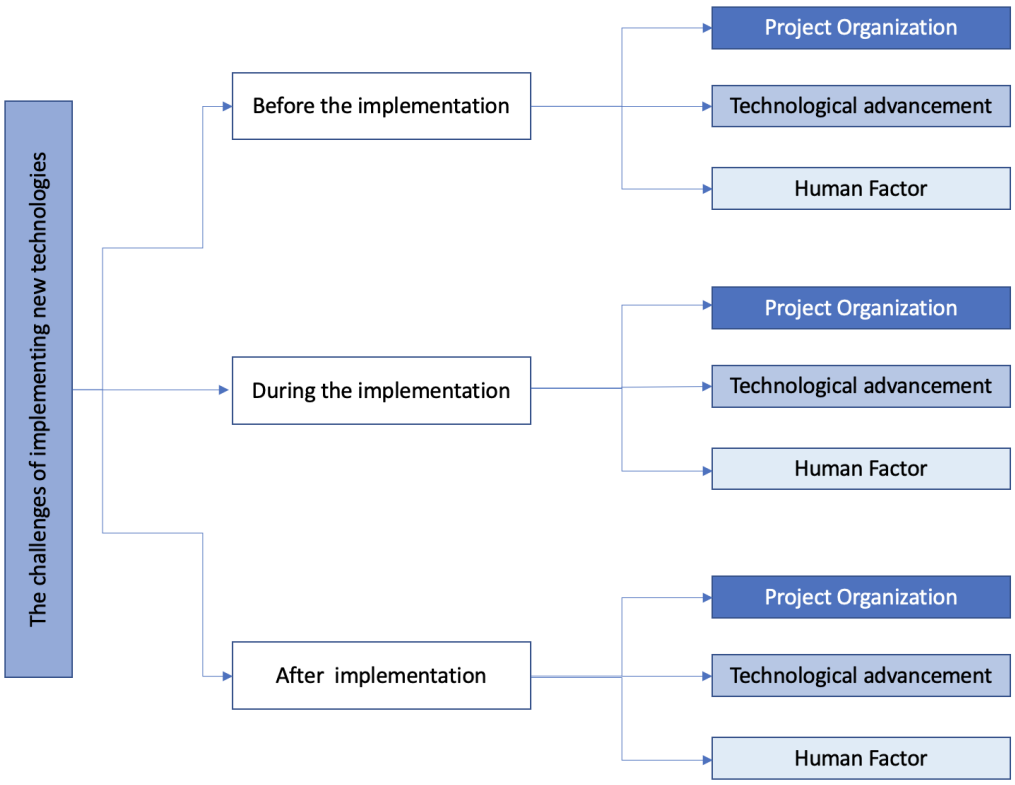

Figure 29: The challenges of implementing new technologies categories

According to the literature study, the challenges of implementing new technologies can be divided into three categories:

- **Project Organization:** Challenges associated with project management, decision making, strategies, and the project outline.
- **Technological advancement:** challenges associated with the technologies

implemented in terms of knowledge, application, and manipulation.

- **Human Factor:** Workplace challenges, including employee reaction to change and adaptation to the new work environment.

In this paragraph we are going to investigate and study these three factors in three main periods of the project : Before / During / After the transition.

4.3.1 Prior to the implementation of new technologies :

Project organization :

- Time Management:

  The project calendar is one of the main issues that the organizational team of a project must deal with. The project to implement new technologies in the case study was under intense time management pressure. The choice and design of the time frame and deadlines was the priority before the implementation and in the early stages of the project! All the other elements of this operation are structured by deciding when each phase begins and ends. This project was divided into 4 phases in terms of timeline, as stated in the introduction to this paragraph.

  The delivery of the new technologies and the constructions, in theory, were both on schedule. However, the testing period, which is crucial for the development of the new technologies for warehouses, was shortened from 4 months to 1 month. The managing team faced a significant challenge as a result of this change because they had to complete as much testing as they could in only four times the time planned.

  Some deliveries and suppliers were affected by the COVID 19 situation, but not in a way that directly affected the opening date.

  The initial opening week in November 2022 was the scheduled date. But the project managers decided to delay the moving until the end of November 2022, when the opening would take place, as a result of these delays in the testing phase and the difficulties with the technology implementation from an IT perspective.

- Cost Management :

One of the primary reasons the management team considered investing in new technologies was the costs associated with managing the warehouse and carrying out daily operations. The efficiency of the space management was the main issue with the old warehouse and manual material handling techniques. Furthermore, because of the margin error that manual picking allowed, the warehouse lost more money than if it had invested in new technologies that would have reduced those expenses in the long run. Also, since employee salaries make up the majority of the hospital warehouse's costs, reducing the number of operators was a goal in and of itself.

As important as it is, cost effectiveness was a key consideration in the tendering process when choosing technological advancements suppliers. As an example, the project management team chose the SAP WMS (warehouse management system) standard basic version for the new warehouse as a cost-saving measure. The testing period and how challenging the SAP was for the managers and operators, however, brought up another issues and challenges. (Discussed in more detail in the paragraph that follows).

- Scope Management:

  One of the first difficulties the St.Olavs warehouse management team encountered was scope management! and consumed the majority of phase 1 (4 years). Making a decision about exactly what to do, how to do it, and how to present the project's limitations and benefits was crucial. Weighing in on the various parties and stakeholders in the project (the ST.Olav hospital, the warehouse logistics team, Helse Midt Norge, etc.).

- Communication:

  Communication is absolutely essential from an organizational perspective! Additionally, it becomes even more important to ensure that all parties and stakeholders are kept up to date on the project's objectives and advancements when it comes to the implementation of technological advancements.

  The use of technologies implies the presence of an IT team and necessitates a high level of expertise in this area for both using and selecting products, which shapes the criteria for selection. This communication between the logistics team and the IT team was a very big challenge for the St.Olavs logistics center project! According to the warehouse manager, it could have been done more effectively if there had been clearer communication. It is also crucial for non-IT professionals to ask questions and take their time making decisions, particularly when it comes to choosing the right technologies and defining the project's timeline.

Technology :

- Complexity:

  As we noted in the literature review, some technologies can be inherently complex, which can make them challenging to use and comprehend. This may present specific difficulties for the managers, operators, and developers who work with those technologies. Prior to the implementation of these technological advancements, the complexity of technology use posed a significant challenge for the study case under investigation.

- Compatibility:

  The compatibility of all the products with the WMS is also the primary requirement to make things work when various technologies are implemented together into an operational warehouse. The St.Olavs logistics center's project management team designated this requirement as the initial requirement for suppliers of technical solutions (storage, picking, packing, etc.) to meet.

  From a different angle, given that we deal with medical products, technological developments must adhere to a number of restrictions regarding the handling of materials. For example, the sterile product storage area needs a specific storage temperature, pressure, and isolation from all the other factors that might affect the quality of the products, and this directly affects the safety of hospital patients.

- Security:

  The hospital warehouse's important and sensitive data was one of the security challenges this transition brought about. A major challenge that the project also encountered from the start was making sure that all the purchasing, safety stock levels, and information received from all the regional hospitals were safe in light of the rising number of cyberattacks and data breaches.

  Another aspect of these technological advancements is the hardware part: VLMs, AGVs, robots, etc. All of these machines must coexist with human operators without posing any threat to their physical safety. Similar, for instance, to the storage of large products. A very heavy pallet could fall from the fifth row of the storage aisle with just one mistake in the system's data, posing a serious safety risk.

Human Factor :

- Lack of clarity:

  The implementation of new technological advancements projects, like any other type of project, is not without its share of uncertainties in the beginning. The human factor is impacted by factors like the types of technologies that will be used, the knowledge that will be needed, and the methods used to train the operators, how there technological advancement will impact their daily schedule and way of doing things. Due to the problems mentioned in the earlier paragraph earlier, the st.olav logistics project had uncertainties regarding the exact moving date. There was also some uncertainty regarding how prepared the team was for the new platform and how things were to workout after short testing period. The operations manager overcame this difficulty by communicating with the team and being open and honest with them.

- Resistance to change:

  Starting a new project with new technology often necessitates altering current procedures and methods of operation. These adjustments might be opposed by some team members, which could lead to conflict and impede development. To prevent this, the managing team of the study case project implemented a very high level of communication with the operators to ensure that they see these technological advancements as an improvement for their daily tasks rather than a threat and a burden. According to the warehouse manager, regular meetings were held before the transition to present the new project to the operators, address their questions and concerns, and also involve them in the planning process as an active part of this project. This is the crucial element.

  Additionally, because they work in the medical industry, the operators of the St. Olavs warehouse recognize the influence they have on the patients' journey to the hospital or ER department. and "when it comes to the human factor, this is something very particular and distinctive about the hospital warehousing operation" the warehouse manager confirms.

- Skills training :

  The level of expertise needed to operate the new processes in a new high-tech warehouse does necessitate a specific and well-designed training period to get the entire team of operators ready to take on the work. The St.Olav logistics center management team did plan a significant amount of training sessions for all the operators before the transition. But the challenge was in their situation

related to two things: the reduction of the testing period time impacted the training period too, which was insufficient, and also some parts of the systems were not testable before the warehouse was fully operational.

4.3.2 During the transition to the new technologies (The implementation period) :

Project Organization

- Time Management: The scheduling and project calendar that were previously planned are tested and challenged during the transition period. Since this is the first time the system has been used in a real-world setting, there is a high likelihood that events will turn out differently than anticipated, endangering all remaining project deadlines and schedules. This presented a challenge and had an impact on the case study timeline. The testing period took longer than anticipated because the first tests didn't go as planned, and a lot of system failure appeared. This directly affected the opening period, which was postponed from the first to the last week of November. The team's adaptation to the processes, the demand from the clients, the suppliers, and the expectations of everyone to deliver are all factors that affect time management during the transition.

- Cost Management :

  The transition to a new, high-tech system did call for more operators. The project management team needed to increase the warehouse's capacity for a variety of reasons, and since this required more operators, the cost of the paychecks increased. Furthermore, it is crucial to note that because the system is still in its infancy, the operators are still undergoing training, the WMS (warehouse management system) tests are still being updated, and many problems remain unresolved, there is a high likelihood that deliveries will be made incorrectly during this time. This results in a greater number of returns from hospitals that don't receive the correct item, which raises costs for the warehouse.

- Communication :

  The most difficult aspect of the project and one that continues to be of utmost importance is communication, which must be carried out on two levels: First, communication with all project stakeholders. The study case team manager

had a difficult time maintaining a clear line of communication with, for example, the IT team. It wasn't clear what was expected of each team in terms of testing periods and how well-suited the solutions are to the medical industry and to the operators.

Second, the internal communication with the operators: It is crucial for the managers to maintain the team's motivation and inform them of what is happening and how they intend to overcome and solve the challenges faced. it's during the transition period when a high number of technical issues, failed tests, and system failures occurs. The St.Olavs warehouse manager thinks that "being open-minded, and honest about both the good and the bad things happening with your team is the key to get over this challenge".

Technology

- Complexity and Compatibility:

  The transitions section is practically where the complexity of technology first appears, since the system is now operating in a real-world settings. As previously stated and for financial reasons, the managing team chose to use a standard SAP system in the new warehouse rather than one that was customized for the medical warehousing operation. As a result, the solution was not tailored to the flow of materials. The system fails on the first day of testing, and because it took a long time for the IT team to fix all the issues and fails with the SAP system, the testing period has been reduced from 4 to 1 month. On the other hand, because the technology has not been adapted, the operators have struggled to manipulate it, and the team manager states that "these solutions are not made for my team." The main challenge to face during these types of transitions is a high level of complexity and a lack of adaptation of the technology to the user.

- Security :

  When it comes to security, and at this stage of the project, it is one of the first factors to be tested, and all requirements must be met before proceeding with testing and operations. Another aspect of security that technology has is the impact on the region's health security. The regional warehouse's logistics center is the main source of products and the main supplier for all of the region's medical infrastructure, so if the technology fails to work, especially in the beginning, the impact is direct on the hospitals and puts the health system at risk. This is primarily because hospitals have limited storage space and must order products on a daily basis for operations and medical treatments.

Human Factor

- Lack of clarity :

  All of the challenges that this transition brings, such as the first contact with technology, bugs in the SAP system, and the way operations appear to be difficult and not working optimally, cause a lack of clarity for the team and especially for the operators. Since the project, which was described as a source of better material handling and working conditions and promoted to be making life easier, appears to make things more complicated during the transitional

period. This challenge will necessitate a lot of help, motivation, and most importantly, a prediction from the previous step of the project.

The warehouse manager of the case study confirms that the way to overcome these challenges is to first communicate clearly with the team and include them in the project and what is going around them. But also, make sure to hold numerous meetings prior to the transition, to prepare the operators mentally and physically to face all of these problems. and make sure to show them that the transition is a must to go through before reaching the optimal working system.

- Resistance to change :

  The literature review demonstrates the various reasons for resistance to change, as well as how operators can and do perceive technology as a threat to their comfort zone and daily routines, which results in resistance to change and refusal to learn and upgrade the new systems. However, there is one factor that does change the situation in the medical field.

  According to the logistics management team, the operators were fully engaged in the transition, open to it, eager to learn, and did everything they could to assist the team leaders in overcoming the challenges that the transitional period brought. This is due to the pride they take in their work, not only as logistics workers but also as health care workers. The fact that each item chosen correctly has an impact on the doctor's work in the operating room and, implicitly, the life of a patient makes the operators very cautious and proud of what they do on a daily basis.

4.3.3 Following the implementation of new technologies :

According to the project management team, the transition phase of the project was still in progress at the time this study was conducted, but it had already reached a very advanced stage. So the majority of the challenges and conclusions in this paragraph were based on the project leaders anticipations during the interviews, and the information collected in the literature study

- **Project Organization**

  In terms of project organization, following the transition, the team begins an evaluation of the effects of the technologies implemented, determining how close the results are to the predicted performance. Once the transition period is complete, the St.Olavs logistics center, with the new fully operational capacity will open to new customers and take more orders, gradually adapting to its new capacities. The challenges here are to discover the limits and how far the expansion can go.

  The warehouse manager confirms that this will be done gradually and step by step, starting with a limited list of products that can be purchased from clients and gradually expanding based on warehouse capacity and productivity.

  On the other hand, from an organizational standpoint, it is critical to evaluate the various parts of the project to determine what went well, what went wrong, and what could have been done better in order to avoid repeating the same mistakes in future projects.

- **Technology**

  Once the project has reached its peak performance, technological advancement necessitates long-term maintenance and upkeep. Updates and upgrades of systems, particularly software, are critical in this regard. And, in order to maintain coherence with project management scaling, because the warehousing aims to explore new customers and expand to other private clients, the SAP system and technologies will present a challenge to adapt, upgrade, and explore the limits of the current infrastructure.

- **Human Factor**

  The most important challenge for the human factor after the transition is to have as flexible a team as possible, which includes having all of the operators master the majority of the tasks and technologies in the warehouse. According to the inbound and outbound section managers, once the transition is complete and the system is fully operational, the priority is for all operators to

be able to manipulate and work in all of the different positions. The logistics center managers hope to have this training completed by the operators themselves. The goal is for them to teach each other and share all of the practical knowledge they have about the various technologies and positions (picking, packing, storing, shipping, etc.).

4.4 The effects of implementing the technological advancements in St.Olav logistics center:

To investigate the effects of incorporating new technologies into the hospital warehousing operations, the study case compared performance and working conditions before and after the implementation. All of the KPIs in the previous paragraph and earlier theory that were deemed relevant and important for the medical fields logistics were investigated and compared to the one in the old warehouse. Aside from the data, the interviews with the warehouse management teams assisted in determining the other effects concerning processes, material flow, the supply chain performance in general, human resource scheduling and the operations management in the logistics center.

The new logistics center has yet to achieve full performance and optimal flow, according to the project timeline, and at the time of this research project. The transition is still ongoing, but it has made significant progress. This explains why some KPIs are not available, have lower values than expected, or are non tracked from the warehouse at this stage. The conclusions regarding those KPIs were based on interviews with the management team and the trend of numbers during the transition period of the case study project.

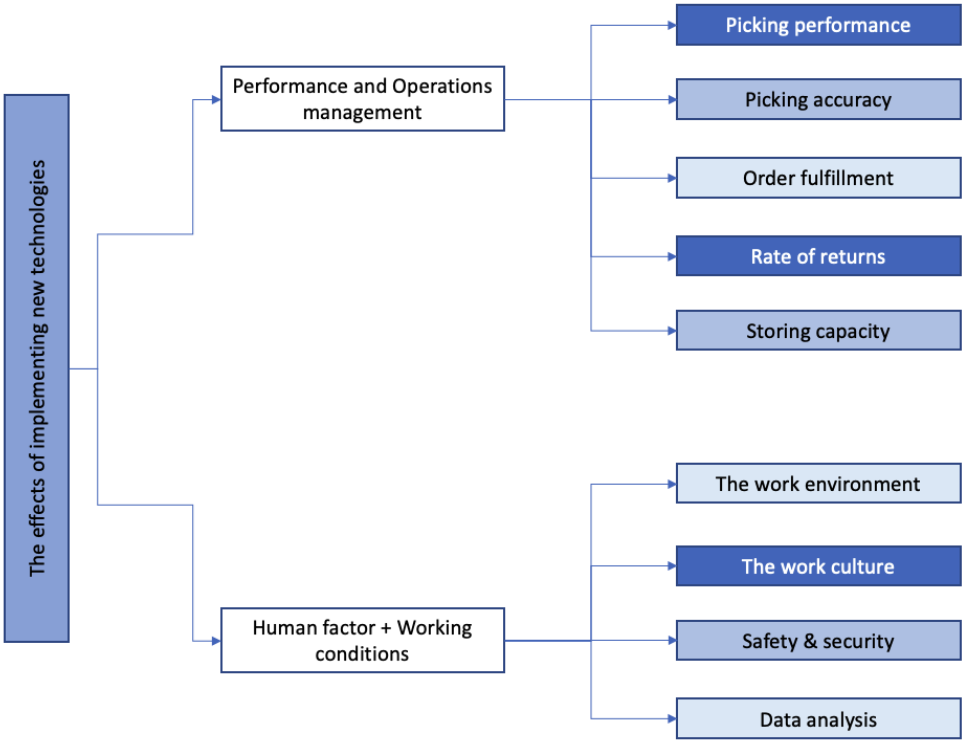

Figure 30: The effects of implementing new technologies

4.4.1 Performance:

- **Picking process :**

  In the new logistics center, and following the implementation of new technologies, the picking process is managed using scanners and electronic tablets rather than manual control and a paper check list.

  Once the picking order is released, the order will be assigned to the first available picking operator.

  Based on the three main products and order categories that the warehouse prepares and sends to the hospitals, the logistics center has three main picking processes: "sterile products" stored in the "VLM (Kardex)", "regular products" stored in the "VLM (Kardex)", and "regular products" kept on the "high rack" zone.

  The performance of the picking process was difficult at the start of the transition due to all of the challenges mentioned previously. The graphs below depict the evolution of picking performance since the first day after the new picking technologies were implemented. The average picking time used by the operators on a daily basis to prepare orders and pick them from each zone of picking is used to calculate performance. The timer starts when the operator accepts the order and ends when it is declared fully picked and ready to ship.

  Sterile products: (VLM - Kardex)

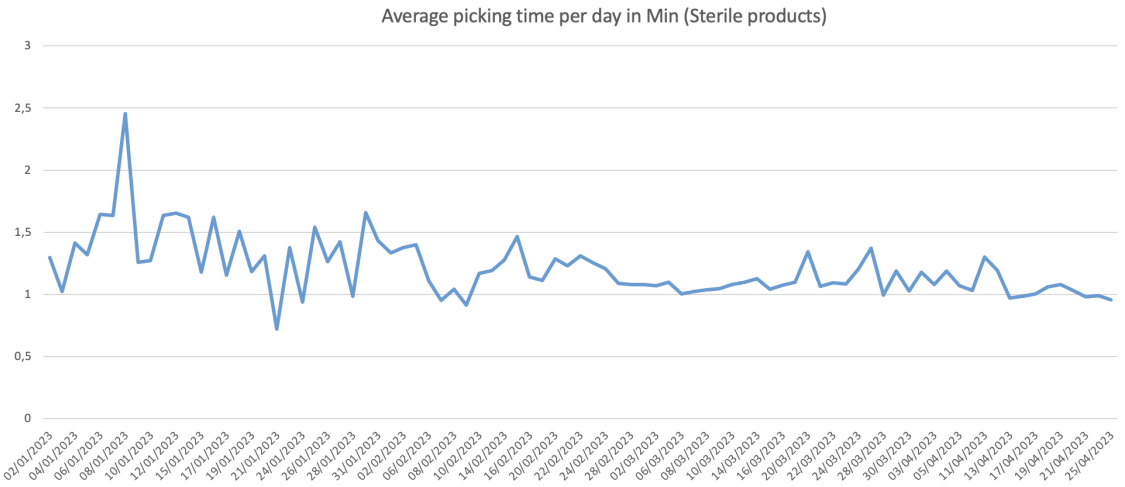

Figure 31: Average picking time per day for the sterile products

The transition period for the VLM picking process of the sterile good was quite unstable, and the average picking time was long. However, since March 2023, the fifth month following the transition to new technologies, the picking

time has been less than the fixed limit of 1,5min. And we can see that the average picking time for sterile goods is getting lower and lower, implying better performance after the transition period.

Regular products: (VLM - kardex)

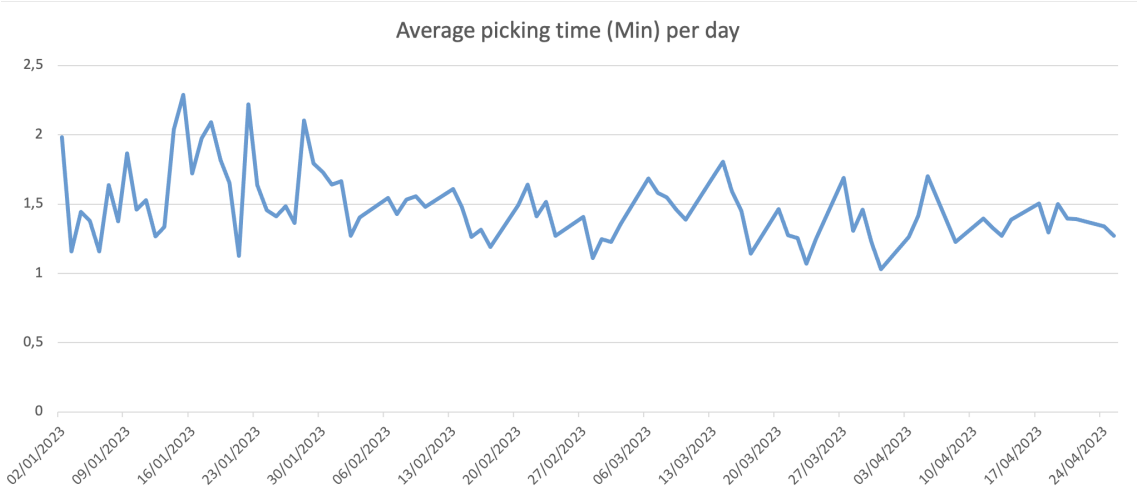

Figure 32: Average picking time per day for the regular products picked from the kardex

The transition period for the VLM picking process of non-sterile goods appears to be similar to that of sterile goods. This is due to the use of the same VLM system. It is simple to manipulate and has a low margin of error. The beginning was also challenging, but once the team became acquainted with the VLM and its manipulation, the picking speed increased and the time decreased. And, in the long run, picking time is expected to decrease.

Regular products: (high rack)

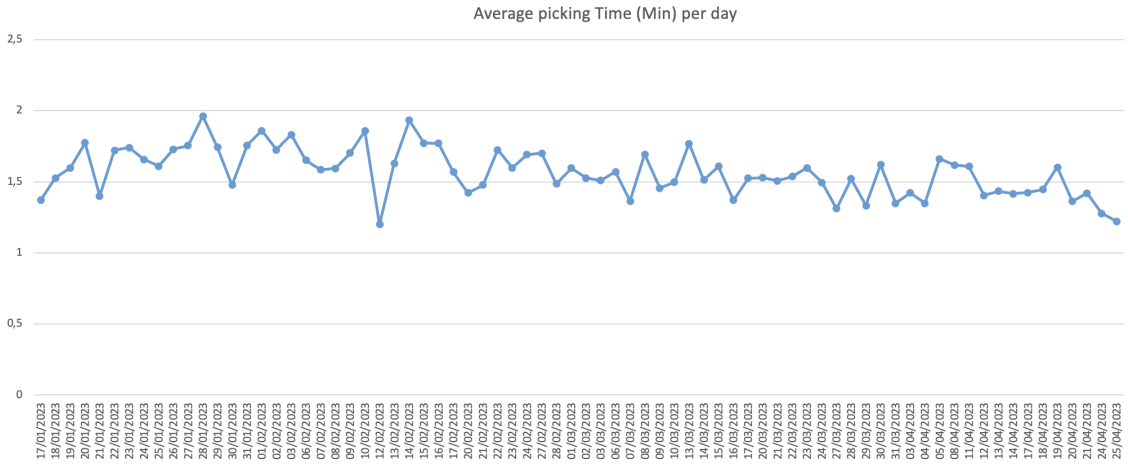

Figure 33: Average picking time per day for the regular products picked from the kardex

The transition was not as difficult for regular products because the high rack system was already in place in the old warehouse. However, the layout and structure have been improved, and the picking tools are now numeric and allow for zero error because scanning the item before picking it is required. The performance followed the same pattern, and it began to decline after the third month. The average picking time is still longer than the VLM picking order, which is due to the longer travel distance and larger product size for the shelves picking system.

At the time of this study, the warehouse still lacked the AGV's that allow access to the fifth floor of the storing area, so this zone is not fully used yet, waiting for the delivery from the supplier.

The Effect of technology on the picking process:

The investigation show that the effect is positive and do show up after the transition. The managing team and so is the theory do predict it to get better and better in the coming day with a lower rate of problems related to the system that impact directly the material handling and the operations during the shift.

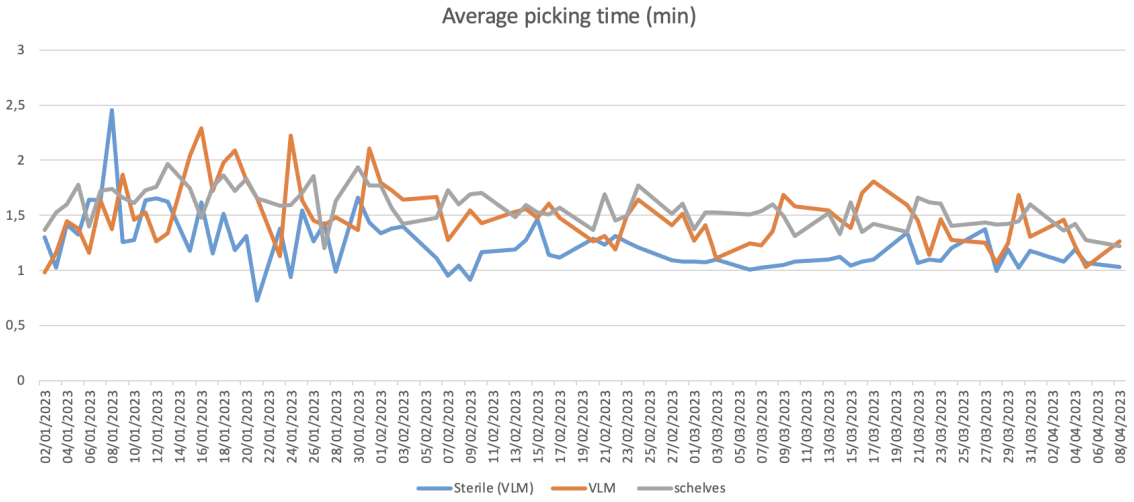

Figure 34: Average picking time per day for all the picking processes

Picking accuracy:

Picking accuracy KPIs are an important factor in medical warehousing operations. As shown in the figure below, prior to the implementation of technological advancement, accuracy was never 100% and there was always a margin of error when it came to order picking. Following the implementation of technological advancement, and beginning in week 1 of 2023, the accuracy increased to 100%. This is because the system does not allow to pick an item before scanning its bar code, so the operator cannot pick the wrong item because the system will not accept / allow it.

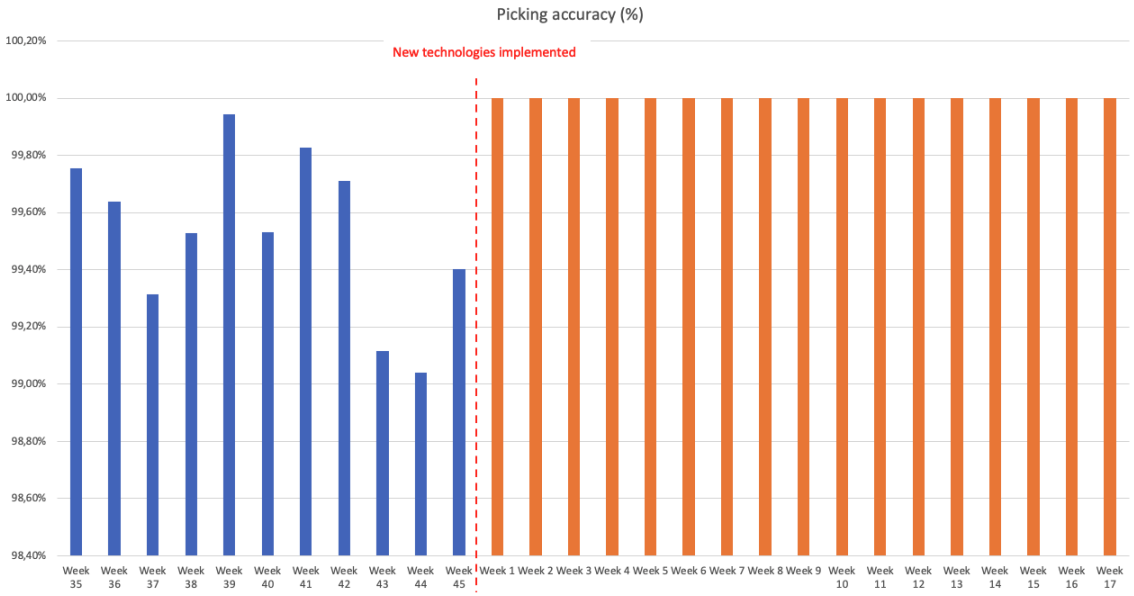

Figure 35: the picking accuracy before and after the implementation of the new technologies

- **Order fulfillment:**

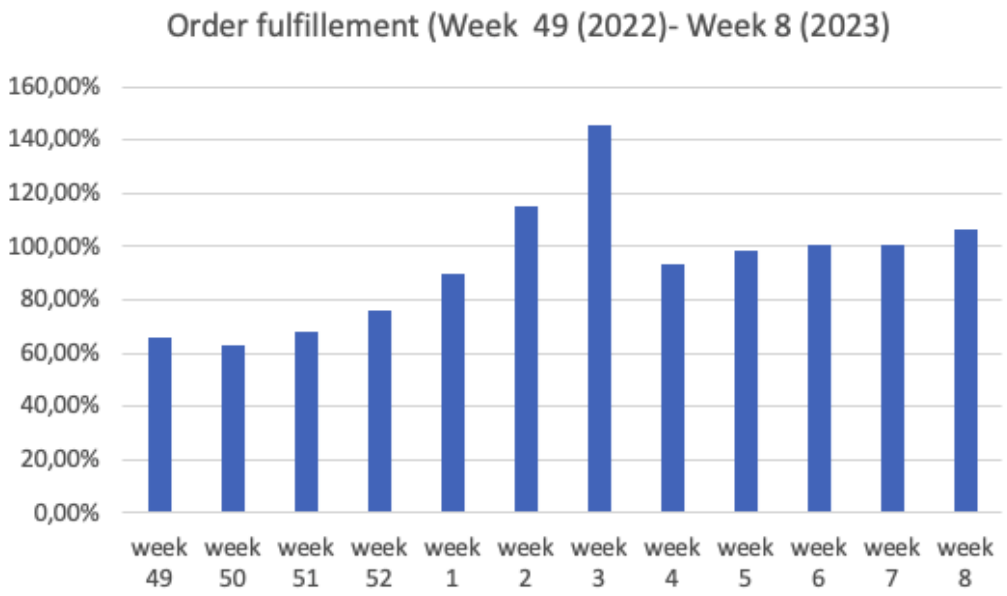

Figure 36: The fulfillment order evolution

One of the most important and critical indicators for the hospital warehouse is the order fulfillment KPIs. Orders from hospitals are usually important and necessitate a highly accurate delivery system. There were a lot of problems in the process after the implementation of new technologies and moving to the new logistics center, and due to all of the reasons stated in the challenges chapter (4.3), especially the one related to the WMS not functioning properly,

that led to the order fulfillment rate being very mediocre at the beginning (from week 49 to Week 52). According to the management team, this was a very difficult period because when the hospital department did not receive the expected order, they used the emergency orders line to send it, which strained the operations management in the warehouse and resulted in an accumulation of requests and orders. From the first week of 2023, the process began to improve, and the effect of the new process improved steadily, eventually reaching 100%.

PS: *The order fulfillment rate was higher than 100% in weeks (2and 3) since the warehouse was sending all the orders delayed from the previous weeks.*

- **Fulfillment accuracy**

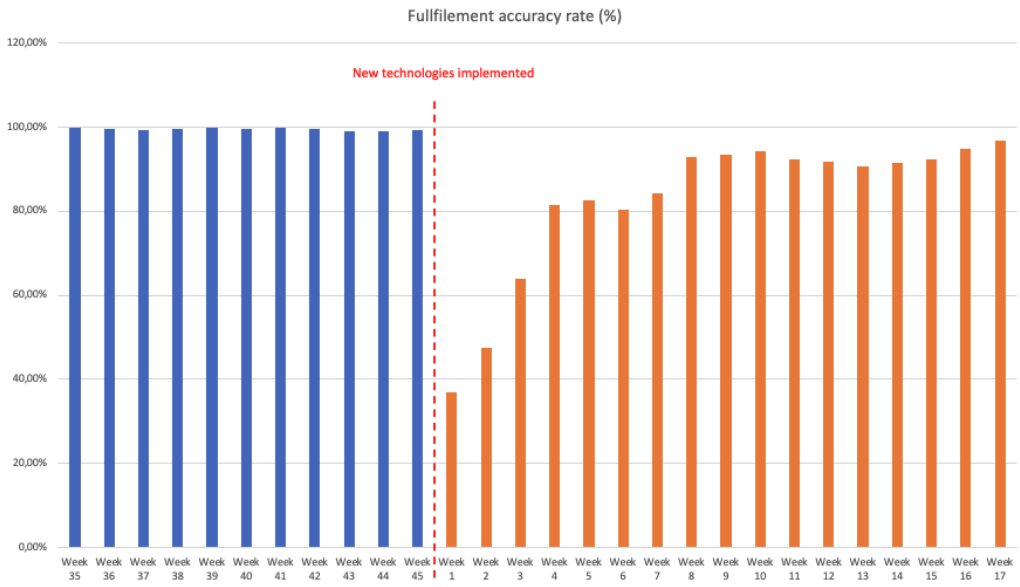

Figure 37: Fulfillment accuracy

For the fulfillment accuracy, as the order fulfilling KPI, it was heavily impacted during at the beginning of the transition and dropped from 99% to less than 40%. this was mainly due to the WMS issues and the lack of knowledge when it comes to the manipulation of the scanners and tablets as new tools of picking and preparing the orders. Major technical issues in the outbound section also caused more negative impact on the fulfillment accuracy.

It is also important to highlight that the outbound section was not tested prior to the implementation of new technologies and the permanent relocation to the new logistics center. This resulted in a large margin of errors and performance issues. The team had to ignore the system and do things manually on occasions in order to fulfill the urgent orders from the St.Olavs hospital. Beginning in week 8, the trend of order fulfillment began to return to normal, and it

kept getting better and better. We still haven't reached the previous level of 99.9% registered in the old warehouse, but that's primarily due to the ongoing transition, unresolved system issues, and the constant addition of new clients and hospitals to the new warehouse.

- **Rate of return:** This KPI is not tracked at this stage of the project, so the team could not provide any data regarding it. However, according to the management team, the rate return is much better and lower than in the old warehouse, and this is due to the new system's 100% picking accuracy. Still there is always presence of items that are either no longer needed by the client or damaged.

- **Storing capacity :**

  The new logistics center, with the technological advancements regarding the storing facilities in the different areas and types of products , for instance VLM, high rack does allow a **10 time more storing capacity** .

  (the exact number were not shared for confidentiality reasons)

4.4.2 Human factor and working conditions

- **The work culture in the medical field :**

  One of the most important characteristics of the work culture in the medical warehousing field is the workers' pride in their jobs. For example, the logistics center's warehouse manager states, "our teams take pride in their daily work, and we all feel the responsibility we all have as a warehouse in making the journey of patients to the hospital a safe one."

  In contrast to other sectors, the high picking accuracy and service level required by the medical field occur in the energy level that the operator provides in their task. However, this sense of responsibility comes with a high level of stress and responsibility. Since if a wrong item picked , delayed or sent with the wrong truck might put a patient life is in danger in the emergency room. As a result, the effect of technological advancements can be seen in the higher service level and the extremely low picking error and mistakes.

  In the old warehouse and with the manual system, operators had to find the spot, make sure it was the correct item in the right place, check how many safety packaging layers were to be kept before picking the product, and register the product picked by hand on paper. When we add the time requirement and the risks associated with picking the wrong item to all of these processes, the stress level can be "mentally exhausting" for the operator who goes through this operation on a daily basis.

  It is not possible to pick the wrong item or find the wrong item in the wrong location with the automated picking system and scanners. This will allow the team to work in a less stressful environment when it comes to order picking and fulfillment.

- **Safety and Security :**

  In terms of safety, the impact of new technologies can be seen directly in the material handling and the low risks the new process poses to the operator's health. The VLM system, for example, allows for direct product picking to the picking trolley, without any issues with carrying or weight. AGVs also allow for automated material manipulating when handling heavy materials.

  The SAP system in the storage area allows for effective management of product storage in high rack picking. The WMS places the heavier products on the lower shelves and the lighter ones on the upper shelves, lowering the risks and dangers of any potential accident in the storage area.

  From a security standpoint, hospital warehouses are regarded as a critical and sensitive location for the region's and country's health security. Because of the

importance and value of the products stored in these infrastructures, security is a top priority. With technological advancements, the managing team of the St.Olav logistics center has a better overview of the stock level, as well as a better and more accurate understanding of the safety stocks, what to order, when, in what quantity, and from which suppliers.

The information about the safety stock levels is kept private and requires a high level of security to access. This feature is enabled by advanced technology software, which provides greater security for those data.

- **Data Analysis**

  The new technological advancements, and through the WMS (SAP in case of the study case) allow access to a large amount of data and information not only regarding the storage but also about operations management, material flow, and operator performance.

  These data and information allow the management team to keep track of the operation and intervene in the event of a problem with a process, a machine, or an operator, resolving the issue at an early stage. This has an immediate and positive impact on the working environment and conditions.

  The large amount of data also aids in shift scheduling and forecasting in the short and long run. It's important to remember that the high uncertainty in hospital medical operations makes forecasting accuracy pretty variable, but in general, the more data the logistics center has, the better the scheduling. Allowing for the proper number of staff and operators while avoiding overworking or overstaffing.

4.5 Summary of the study case :

This case study supplemented the thesis literature review by narrowing the scope from general warehousing operations to hospital warehousing operations. The St.olavs hospital logistics center project is an excellent example of a hospital warehouse that underwent a project of technological advancement implementation.

We highlighted the "operations management in the hospital warehouse" specifications in this study case. The main result of this section is that the material handling conditions and high service level required are what distinguishes medical warehousing operations from others. The main pillars of medical warehousing are accurate suppliers, strong safety stock, accurate picking, and a very high service level. We also identified the most important key performance indicators for medical warehousing operations and investigated them later based on the study case results.

The following section of the chapter looked into the challenges of implementing a technological advancement project. Before, during, and after implementation, the challenges can be classified into three categories: "project organization," "technology," and "human factor." The project managers must be aware of these challenges and devise a strategy to overcome them (see the discussion section in the following chapter).

In the third block, the paper investigates the effects of new technology implementation on hospital warehousing operations based on the data and interviews conducted. Better picking accuracy, higher order fulfillment and responsiveness, 100% fulfillment accuracy and a lower rate of returns. To this, we can add the increased storage capacity (due to VLMs), better working conditions, safety, and security.

This project implementation allowed the regional health care system to have a better and higher quality of service, better collaboration with the supplier, more insight on demand and forecasting (because everything is tracked), and the logistics center is also working on accepting more private clinics and regional hospitals because the warehouse capacity has been upgraded compared to the old infrastructure.

However, it is important to note that all of these conclusions are based on the warehouse's performance continuing in the same direction of evolution. The SAP system still has a lot of challenging tasks to be fixed, some technology deliveries (for example, AGV's) have not yet been all delivered, the tracking of returns has not yet been fixed... these are all challenges that remain at this stage of the project

unsolved.

The study case also highlighted many of the common mistakes that occur during this type of project and that the management team had to deal with and learn the hard way, particularly during the implementation and transition phase. This will be the goal of the following chapter: to use the findings of the literature review and the case study to construct a framework for implementing technological advancements in the medical field.

5 Discussion

This chapter discuss and confront the outcome of the previous parts of this report , literature and case study in order to answer the research questions stated earlier.

5.1 The challenges of implementing technological advancements into the hospital warehouse

When it comes to the challenges of implementing technological advancements to warehousing operations in general, both the literature review and the case study conducted agree on three major categories of challenges the projects face: "Project Organization" challenges, "Technological" challenges, and "Human Factor" challenges.

The study case focuses on medical warehousing operations or hospital warehousing operations and introduces specifications to this field. The material handling conditions, the high accuracy of picking, and the high quality of the delivery service are what distinguishes these critical projects.

The case study did introduce the fact that the challenges varied in importance and priority throughout the project time line: before, during, and after the implementation of technological advancements. The table below provides an overview and synthesis of all the findings from this research project in terms of the challenges of incorporating technological advancements into hospital warehousing operations.

Before the implementation:

The main and most difficult part of the project organization in the early stages of planning the project calendar, its deadlines, and how the operations will run. The main challenges are time, cost, scope, and communication management. During this transition period, the team should consider the continuity of operations for supplying and delivering orders to clients (with the same quality, accuracy, and punctuality requirements). This is due to the hospital department's limited storage capacity and reliance on day-to-day orders from the warehouse. This major challenge has an impact on the transition to new technologies because it is one of the specifications of hospital warehousing operations. The three most important factors in technology are complexity, compatibility, and security. with all of the requirements listed in

the table below.

For the human factor, this phase of the project is critical for establishing trust and confidence in order to face the next step, which will undoubtedly be filled with challenges, difficulties, and complex tasks. Lack of clarity, resistance to change, and skills development are all challenges that must be prioritized.

The Challenges of implementing the technological advancements into the medical warehousing operations		
Before the implementation	Project organization	• **Time Management:** Project calendar, deadlines, phases of the project, Choice of the suppliers and tendering process, Delays during the construction period • **Cost Management:** Optimize the costs, respect the budget, ensure the high quality required by the medical field, selecting the suppliers having the best compromise (quality, price) • **Scope Management:** Define what are the objectives of the transition, why and how the team will process, draw the line of what solutions are to be implemented and with what criteria and requirements. • **Communication:** Update and include all the stakeholders in the advancement of the project, make sure everyone understands the technical terms and requirements involved in the project (especially regarding the IT part), state clearly the objectives and the outcome expected.
	Technology	• **Complexity:** Choose the right technology to the right process, have the simplest and most efficient technology to manipulate and use (for the managers and the operators) • **Compatibility:** Compatibility of the new technologies with the existing process such as: the warehouse management system, the material flow, warehouse layout, the sterile zone requirements and the medical field material handling conditions (temperature, pressure, isolation, quality and high accuracy) • **Security:** DATA management and access, the coexistence of AGV's and robots with the operators
	Human factor	• **Lack of clarity:** Uncertainties regarding the deadlines and delays, knowledge required, manipulation of the new processes, how ready the team to such transition. • **Resistance to change:** Refusal of change, fear and being uncomfortable, see technology as threat. • **Skills training:** The right training to the right process with the right monitor, enough training time, usage of the correct testing conditions (the closest to the real operations)

Table 4: The challenges before implementing

During the implementation:

The main project organization challenges in the next phase of implementation revolve around putting everything that has been planned, scheduled, purchased, and supplied into real-world conditions. This typically raises many issues regarding time management (due to delays and system failures, physical implementation of new materials, and a training period that may be insufficient). This impact on operations management has a direct impact on delivery quality, adherence to departure schedules, and on-time delivery. As a result, teams typically hire more people to meet these challenges, resulting in an increase in cost management. In terms of technology, the IT team is putting the entire WMS (warehouse management system) to the test in real-world conditions, attempting to feed it as much data as possible so that operations run as smoothly as possible. The complexity of technology and compatibility issues are always present. For the human factor, the change of the working process , the training period and the overtime working are the main challenges.

During the implementation	Project organization	• **Time management:** Confronting the theoretical calendar to real life conditions, delays, rescheduling, longer testing periods, shorter training periods … • **Cost management:** Need for more operators and working force, more returns and wrong picked items (system failure and lack of training), emergency orders • **Communication:** Misunderstandings between the IT team and the operations managers, internal communication (with the operators), problems solving • **Products Suppliers:** Rescheduling of the deliveries, adapting to the low production capacity, communication the new infrastructure storing requirement (dimensions and criteria of the products for the SAP system)
	Technology	• **Complexity & compatibility:** Failures and system errors, testing issues, non-adaptation to the operations and the type of products, complexity, lack of clarity in the guiding instructions • **Security**: DATA management, DATA transmission from the old to the WMS (in case of having one), manipulation of heavy technologies
	Human Factor	• **Lack of clarity:** Complex processes, feeling lost, hard to work as efficient as before (during the transition) • **Overtime:** Longer time to process tasks, less efficiency, longer shift

Table 5: The challenges during the transition

It is very relevant and important to mention that the duration of the transitional period varies greatly and can either stick to the previous plan, but can also take much longer than expected due to all of the challenges mentioned previously, and that solving them will most likely take a long time and a very high level of IT knowledge and investment. And it means a longer period with a high risk of inaccuracy, delays, unpredictability, extra workforce, overtime... and this is exhausting for both the operators and the project managers. This is why, according to both the literature and the case study, the transitional period is the most critical and challenging.

Following the implementation :

The third section is centered and focused on the project's evaluation. Following the system's full performance, the management team's next challenge will be to determine how far and compatible the results are with the goals and objectives of the new technological advancement project. The next major challenge is to design and implement the new operating system's full capacity, performance, and limitations. What has been accomplished, what has not been accomplished, and, most importantly, how far can we go with this technology?

Maintenance, upgrading, and expansion possibilities are the main challenges that arise and must be addressed for the technologies implemented in the long run.

At this point in the project's development, the operator and the human factor in general enter the phase of normalizing the new working process and developing good working habits. As the team becomes more acquainted with the new environment, they begin the process of exchanging system knowledge and hacks.

Following the implementation	Project organization	• **Evaluation:** Full capacity evaluation, performance, limitations, confrontation of the results and the objectives of the project • **Suppliers:** Adapt to the new capacity, adapt to the new working schedule, adapt to the new products information required from the WMS • **Clients:** Ordering schedule, returns and repayments, choice of products
	Technology	• **Maintenance** • **Upgrading/Updating** • **Expansion possibilities**
	Human factor	• **Build the good working habits** • **Know all the processes** • **Exchange the knowledge**

Table 6: The challenges after the implementation

5.2 The effects of implementing technological advancements into the hospital warehouse:

The second research question of this master project focuses on determining the effects of incorporating technological advances into hospital warehousing operations. Both the theory and the case study provided information, different insights, and data on this topic. The two parts will be confronted in this discussion section. The theoretical effects presented in the literature section will be investigated using the relevant KPIs identified in the study case and confirmed or denied as a benefit or disadvantage of the project implementation.

The literature chapter do sum up the key benefits of the implementation of technological advancement into the warehousing operations can be listed as the following:

- Reduce error rate (better accuracy)
- Improved efficiency
- Increased warehouse productivity (capacity)
- Reduced processing time (lower picking time)
- Maximized space utilization
- Better inventory management
- Reduced operational costs
- Higher safety
- Better order fulfillment
- Long term sustainability
- Fast scale up
- Higher resilience
- Better working conditions

The table below shows each effect along with the relevant KPIs that can be used to investigate its effect and the outcome of the study case.

The effect	Relevant KPIs	Outcome of the study case
Better accuracy	Picking accuracy	**Before:** Average of 94% **After**: Average of 100% **Effect**: Beneficial **Outcome**: Better accuracy
Improved efficiency	Fulfillment accuracy	**Before**: Average 98% **After**: 99% **Effect**: low during the transition, but reached a high value after. Aiming for 100% on the long run. **Outcome**: higher and better fulfillment accuracy and efficiency
Better order fulfillment	Order fulfillment	**Before**: 66% **After**: 100% **Effect**: The order fulfillment, after starting in with low value, it did reach the objective of 100% right after the week 5. **Outcome:** 100% Order fulfillment!
Increased warehouse capacity	Storing capacity	The figures were not shared with us due to confidentiality concerns, but the ratio is ten times higher. **Outcome:** 10 times higher capacity
Better inventory management	Inventory management	**Before**: lack of truck, inaccuracy of manual control, non-registration of the returns to the system **After**: full control of the returns based on the SAP (WMS). The KPI of inventory is not available yet. **Effect**: Not investigated but expected to have higher and more accurate track of the inventory management.
Faster material flow	Picking speed	**Before**: Average of 2min per order **After**: Average 1.2 min per order **Effect**: The picking speed went down for the three different picking processes (sterile, non-sterile and high rack) **Outcome**: Faster picking process

Table 7: The effects of the new technologies implemented on the warehousing operations of the hospital

Some of the effects could not be investigated using KPIs due to a lack of DATA and numerical information, or because they are more quantitative than qualitative, in which case they were investigated using interviews.

- **Reduced optional costs:**

  One of the primary reasons and goals for implementing technological advancements is cost efficiency. Even though the project itself requires significant investment, the benefits are very cost effective. That's due to the better efficiency, higher capacity and faster material handling process. But due to the nature of the operations and the importance of daily order fulfillment for the regional health care system, the study case did show that the cost deduction does not appear, at least during the transitional period. On the contrary, more overtime and extra working capacity have been used to keep up with the regular demand. **So, while this effect is significant, it only occurs over the long term of the project. This is a critical factor to consider during project planning.**

- **Higher safety :**

  There are different ways to see this KPI or factor of safety. When it comes to the safety of the operations, accident risks, and the safety of the operators, the implementation of new technologies values it and provides better working conditions, putting the human factor in more value-added tasks rather than repetitive and physical ones. The advancement of technology has also a positive impact on the storage area and the placement of the products in the high rack, allowing the heaviest and most dangerous products to be stored in the lower parts or specific rooms.

  From the standpoint of product and the hospital patients safety, it is better and more efficient to use the sterile room with technological advancement, and the VLM (Kardex) do allow for a better and more efficient storing conditions in terms of temperature, pressure, and product disposition. One of the new processes introduced with technological advancements into the hospital warehousing operation is the regular washing of picking trolleys, with a tracking system managed by SAP allowing control of how many times the trolley has been used and when it should be sent to the cleaning station.

  However, as technology advances, there are greater risks to the safety of data and numerical information. The more digitalized and interconnected the processes, the greater the threat of hacking and data theft. and this will necessitate more effort on this end! Because hospital warehouses are a very sensitive

infrastructure for the region's health care system and play a critical role in the population safety.

- **Fast Scale Up**

  The project of technological advancement implementation has a direct impact on the performance and capacities of the hospital warehouse. In terms of business, this allows and opens up a wide range of possibilities and growth toward both suppliers and clients. The hospital warehouse could also be open to the private sector, working with private clinics and smaller regional hospitals in the region. So the scale up is a direct effect of the implementation of technological advancement. Still it does require as many factors a some time to reach the full optimal performance.

- **Better working conditions**

  This factor, like many others, is dependent on the position at the time of the project. The study case and theory both agree on the fact that the transitional period is the most difficult. As a result of the stress of learning and manipulating the new system, the technologies not operating at 100% efficiency, and a large number of errors in the system, the effect of technological advancements on the daily work environment can be perceived as negative...

  However, in the long run and after the transition, the effect of new technological advancements does make working conditions better and more relevant, owing to: less repetitive tasks, more value-added tasks for operators, less physical effort and easier material handling tools, and a safer work environment.

Summary

To summarize, and in response to the second research question of this research project, the effects of implementing technological advancements into hospital warehousing operations can be divided into two categories: performance and working conditions. In terms of performance, the effects are positive, and it has been established that technological advancement does allow for improved performance.

The effect on working conditions and work culture in the medical field is also very optimistic and positive, and it has a positive impact on operations.

However, it is critical to remember that most of these effects take time and experience to become concrete and manifest in the warehouse's performance results. As a result, the transition period is difficult and has a negative impact on the overall flow of daily work. Moreover, the medical field, which does not allow for a large margin of error and uncertainties, make leading the project and overcoming this part more stressful.

Nonetheless, the literature and the study case did provide a wealth of insight and information regarding the implementation of technological advancement in a way that avoids the majority of the negative challenges and allows for the reduction of the transitional period and its negative effects on both performance and working conditions of day-to-day tasks; this is what the following paragraph will attempt to address by developing a framework to correctly implement technological advancement.

5.3 A framework of implementing technological advancements into the hospital warehouse

The third and final section of the discussion chapter wraps up all of the previous parts of this research paper and builds a framework, a working method that provides a clear, optimized, and adaptable work plan for the implementation of technological advancements into the hospital warehousing operations based on the literature review, case study, and the two previous research questions addressing the challenges and the effects.

This framework serves as a road map for any project management team seeking to incorporate technological advancements into warehousing operations in general, and the medical field in particular. This road map is divided into three major project phases, as shown earlier in this report: Prior to, during, and following implementation.

The framework addresses the tasks and action plans to be followed in the three levels of implementation: "project organization", "Technology", and "Human Factor" for each part of the project timeline.

The "Project organization" is the project's strategic component. The decision-making process and the planning of how the project's operations and actions will be carried out. The managing team responsible for the project organization, which includes all of the different stakeholders, has the mission of drawing all of the project's time lines, goals, and outcomes.

The term "technology" refers to technological advancements and their application. Many challenges regarding this factor must be addressed at various stages of the project. It is, of course, the focal point of the project and is linked to all of its external and internal factors.

The "human factor" refers to the warehouse's operators and employees. It also includes the management team. They are a solid and central factor to include because they are a part of this transition and are directly impacted by the project's outcome in day-to-day tasks.

The tasks are classified and ordered according to the project's time line, which means before, during, and after. However, some of the tasks do occur concurrently. The tasks with the same number occur at the same time in the framework.

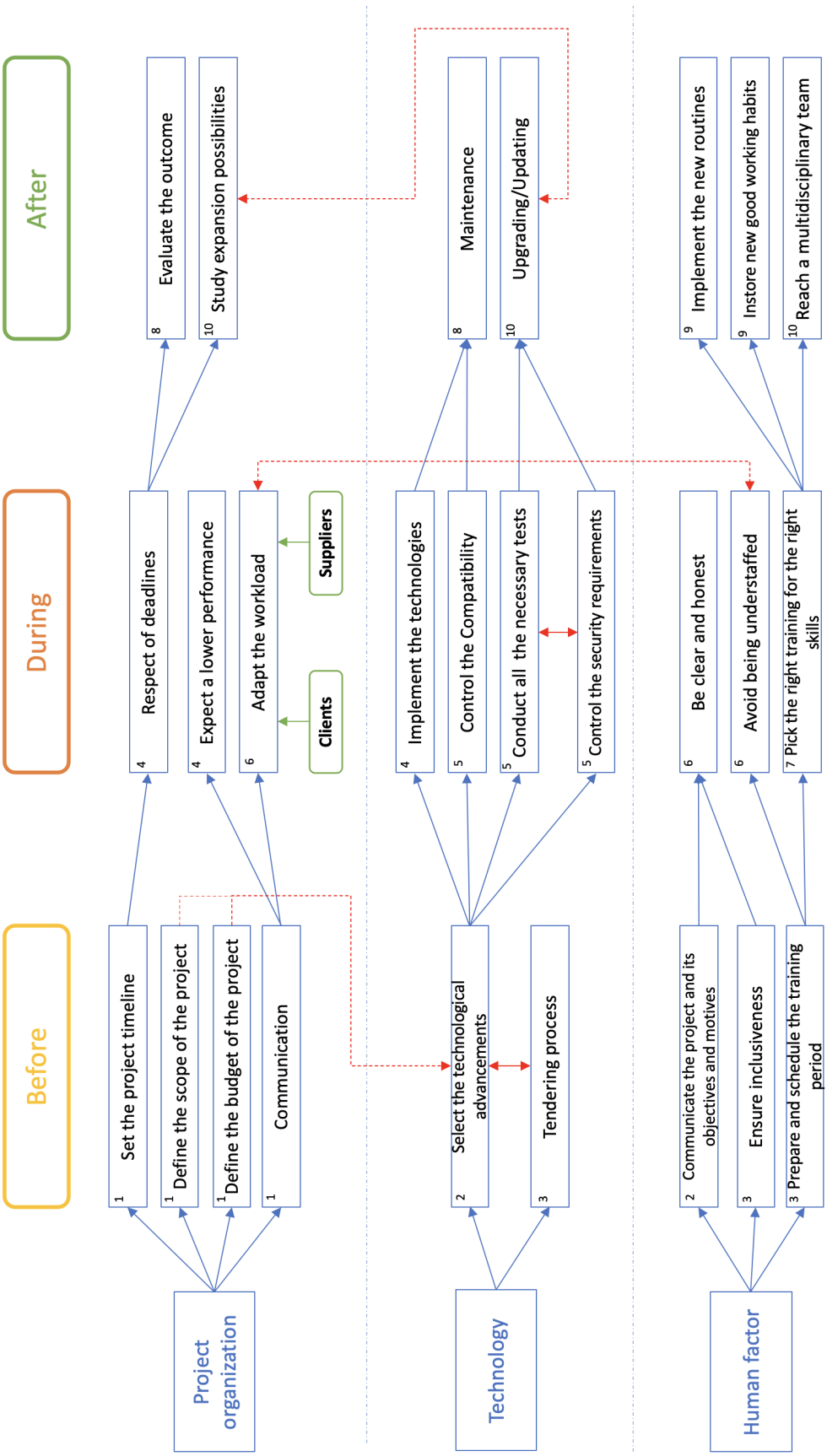

Figure 38: The framework of implementing technological advancements into the hospital warehousing operations

5.3.1 Framework: Before the implementation

Project organization :

- **Set the project timeline :** The priority at this stage is to work on identifying the project calendar and its various phases, as well as what timeline and deadlines to fix. This section includes both short and long-term project planning.
- **Define the scope of the project :** The team must decide which solution to use and which technologies and techniques to implement. (This has a direct impact on technology selection)
- **Define the budget of the project :** To fix the project's budget, quantify the financial needs and challenges, and address the primary sources of funding. (This has a direct impact on technology selection)
- **Communication :** Ensure the flow of communication and information between the project's various stakeholders, and ensure that all parts are aware of and familiar with the project's main decisions and guidelines. In the case of the medical field, this includes the hospital and all of its departments, the warehouse's health care system authorities, as well as external suppliers and IT teams.

Technology :

- **Select the technological advancements:** Identifying the technological advancements to be implemented is one of the most critical and important tasks. Taking into account the project's various factors, such as its goals, objectives, the nature of material flow and operations, as well as the project scope, budget, and timeline. Priority is given to high accuracy, high service level, and control of the material flow and tracking of the products in the various phases of the warehouse in the hospital warehouse.
- **Tendering Process:** In direct link to the preceding point, the tendering process is essentially the selection of the supplier who meets all of the previous conditions and offers the best compromise between all of the requirements.

Human Factor :

- **Communicate the project and its objectives and motives:** The early stages of the project are fraught with uncertainties, a lack of clarity, and apprehension about the unknown. As a result, there is a kind of "resistance to change" that develops. This is why it is critical to incorporate the human factor into the project and familiarize it with all of the upcoming changes. Promote the project and its goals, as well as the need for change and the reasons why this technology is being implemented.
- **Ensure inclusiveness:**Include the human factor in the decision making, and choose, select, and design the new process with a human-centered approach.
- **Prepare and schedule the training period:** Begin planning and scheduling training sessions as soon as possible. Give the training period plenty of time and don't rush through it.

5.3.2 Framework: During the implementation

Project organization :

- **Respect of deadlines:** The previous part's schedule and planning are put to the test in the transition section. And, most likely, things do not go as smoothly as planned, and delays begin to occur. The main goal should be to reduce delays as much as possible, predict them in advance, and have backup plans in place. Many key dates are extremely sensitive and difficult to change, and they have significant implications not only for the warehouse but also for the region's health care system in the case of the hospital warehouse.
- **Expect a lower performance:** Due to the training period, technology implementation, and changes in material flow and handling in the warehouse, the warehouse's performance does drop, and the management team should anticipate this point. One of the most common errors to avoid is expecting performance to remain constant or to see the results of technology since the first day; this is not possible.
- **Adapt the workload:** Because of the preceding reason, it is critical to process the ordering capacity step by step and adjust the workload. And this relates to the warehouse's inbound and outbound operations, which refer to the product suppliers (inbound) and the clients ordering the products (hospital departments). Begin with a list of the most critical and important products required, encourage hospitals to build a small safety stock prior to this phase of the project, and work on expanding the list of products step by step based on warehouse performance with new technologies.

Technology :

- **Implement the technologies:** Suppliers ensure the implementation of new technologies through collaboration with the IT service. It is critical to monitor the quality and final products received and ensure that they are appropriate for the warehouse's internal structure, material flow, and operators.
- **Control and compatibility:** If the suppliers' technologies (hardware and software) are not the same, it is critical to control the compatibility and ability of all products to communicate with the warehouse management system (for example, SAP).

- **Conduct all the necessary tests:** If the testing period is well managed, it can help to ensure a smooth transition. It necessitates the cooperation of the IT team, technology suppliers, and warehouse managers. The new warehouse management system must be customized and fed with existing data. Plan ahead of time each party's responsibilities during the testing period.
- **Control the security requirements:** Check whether the new system certifies and meets all of the safety requirements for the warehouse and the operators during the testing period. Consider digital security and data management as well.

Human Factor:

- **Be clear and honest:** Because the transition period is quite unpredictable and full of uncertainties regarding many different factors, it is critical to maintain clear and honest communication with the operators. When the information is known, it must be shared with them (for better or worse). And because the working culture in medical warehousing is filled with pride, motivation at work is usually not an issue, and trust is always appreciated.
- **Avoid being understaffed :** In relation to "workload adaptation," and because production capacity is expected to be low in the early days of the transition, having more "trained and skilled" workers is critical. That is, to continue supplying the hospital and its various departments with the products they require on a daily basis.
- **The right training for the right skills:** The training should be tailored to the task at hand as well as the operator. The nature of training is influenced by how familiar the person is with technology, laptops, scanners, tablets, etc., what type of tasks they are involved with, and how long they have been working in the warehouse. Some training requires a lot of theory, while others are 100% learning by doing tasks.

5.3.3 Framework: After the implementation

Project Organization:

- **Evaluate the outcome:** At this point in the project, the system has reached peak performance, and the technologies are operating at peak efficiency. The main task is to compare the project's outcome in terms of performance and results to the project's objectives and goals.
- **Study expansion possibilities:** Before completing the project, it is critical to consider the warehouse's expansion potential after the new infrastructure became fully operational. This can lead to acquiring more suppliers (due to the large storage area) or by acquiring more clients (due to the high capacity and performance).

Technology:

- **Maintenance:** To maintain the quality and safety of operations, technology requires and will always require maintenance and control. It is critical to schedule regular technical controls for technological advancements implemented in collaboration with technology suppliers and in accordance with the purchasing contract and its requirements and conditions (regarding prices, etc.).
- **Upgrading/updating:** Technology will be expanded and upgraded in correlation with the expansion possibilities. To keep up with the rising demand, more scanners, picking tablets, VLMs, and so on will be installed.

Human Factor:

- **Implement the new routines:** Following the testing period and the resolution of all issues related to the manipulation of technologies, it is critical to implement a standardized method of performing tasks. A method that is deemed most efficient and least time consuming by the operators and the managers.
- **Instore new good working habits:** As a result of the new standards, operators should be able to adapt and use the best methods of performing and managing tasks.
- **Reach a multidisciplinary team :** To gain flexibility and better understand the benefits of a human-centered approach, it is critical to have multidisciplinary operators who can manipulate multiple technologies and work in various positions along the production line (picking, packing, storing, etc.).

6 Conclusion

This chapter summarizes the thesis' findings and offers closing thoughts. A description of the current research's contributions to theory and practice is included. Furthermore, the limitations of the research process are discussed, and finally, suggestions for future research are presented.

This thesis has investigated and explored the process of incorporating technological advancements into warehousing operations, with a focus on the medical field and its specifications. The three main research questions directed the thesis to concentrate on three main factors: the challenges, the effects, and the framework for implementing technological advancements into the hospital warehouse. The findings of the literature review were related to warehousing operations in general, and the study case focused on the hospital and medical field.

Medical warehouses have the same structure as traditional warehouses, with the main five departments being reception, storing, picking, packing, and shipping. The main differences and challenges are in the material handling and storage conditions throughout the warehousing processes. Temperature, pressure, and sterilization are the most important factors to consider and maintain during the hospital's warehousing operations. Security precautions are much stricter and more stringent. Due to the nature of some products, an anti-fire room that is well equipped to store easily burnable products is also required.

The medical supply chain, on the other hand, has different storing policies, and the safety stocks of medical warehouses are much higher than those of regular warehouses, and inventory carrying costs are not considered because the products must be kept in stock even if they are not used or sold. Simultaneously, the relationship between the warehouse and the supplier is more critical and strict in this situation, and dependability is critical because it involves products with a direct impact on human life/health. The performance quality and accuracy of picking and order handling are stricter, and the margin error allowed is much lower than in a regular warehouse.

The research paper investigated the challenges of implementing technological advancements after developing the specifications of the medical warehousing operations and becoming acquainted with each criteria and their specifications. The timeline of the technological advancements project implementation is divided into three major periods: before, during, and after the implementation. This thesis's findings cat-

egorize the challenges into three categories: "Project organization," "Technology," and "Human factor."

Prior to implementation, the main challenges are related to scheduling and drawing the scope, time, and specifications of the project. It is also critical to choose the appropriate technology for the job. As previously stated, the outcome of this research thesis is to prioritize the high service level, accuracy, and material handling condition regarding the storing condition for some specific products. Communication is without a doubt the most important topic for the human factor that must be included in the transition. The following phase of the project has been designated as the most difficult and critical. The project time line is challenged by delays and unpredictability, technology is put to testing, and many technical issues arise, implying a drop in warehouse performance, and it is critical to have a larger amount of working force capacity to cope with this and ensure the delivery of goods to the hospital. Finally, the third step is to assess the project's success and determine how far the investment in new technologies has benefited the hospital warehouse operations.

The effects of technological advancements were the focus of the second research question. The effects were classified as being related to performance (implicating key performance indicators) and human factor working conditions . The study case results revealed a positive impact, with operations shifting toward a higher capacity and more human-centric approach (putting operators in more valuable and less repetitive tasks). However, the positive effects take time and are dependent on how long the transition takes. As long as this stage is not reached, the hospital warehouse operations are highly impacted and have very disturbed performance, negatively impacting the work environment and the material flow between the warehouse and the hospital departments, as well as the suppliers.

Based on the findings of the previous two research questions, the third research question focused on developing a framework for incorporating technological advancements into warehousing operations in general and the hospital warehouse in particular. Taking into account the challenges identified, as well as the good habits investigated in the literature section and in the study case through interviews with the managers, the framework provides a clear, direct, and coherent working map for the managing team aiming to implement technological advancements into hospital warehousing operations.

Limitations and further research

Given the exploratory goal of the thesis, the findings and contributions are satisfactory because they suggest several areas for further research on the possibilities of incorporating new technologies into medical warehousing operations.

The case study company did provide a wealth of information and insight into narrowing the scope to medical field warehousing operations. However, the nature of the project, its time frame, and the fact that the goal was to assist the transition did not allow for a large amount of concrete data for the project's effects and outcome in the long run. It was also not possible to compare the overall results of the implementation of technological advancements into the St.Olavs warehouse to the project's objectives. As a result, the findings and conclusions regarding the long-term effects were based on the managing team's assumptions and predictions, limiting the generalizability of the findings.

The scope of this thesis was also limited to technological advancements, with no concrete reference to technologies without adressing the full automation possibilities (industry 4.0).

This research project's limitations should be used to guide and inspire future research. This thesis provides a framework for incorporating technological advancements into hospital warehousing operations. More research is needed to determine how valid this outcome is if technology advances to full automation (logistics4.0). For example, investigate how full automation affects productivity and capacity, and how the human factor reacts to a 100% rate of automation.

This research topic argues that implementing technological advancements has a positive impact on performance and working conditions. Further research is recommended to confirm and investigate the optimal automation and technology ratio for the most optimized and effective warehouse operations management.

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Appendix

A Interviews questionnaires

A.1 Inbound Manager

Questions	Timing
Introduction	5 min
Thank you for accepting the interview request	
Presenting the project and its goals	
Can the interview be recorded?	
Do you want to be anonymous?	
Presenting the student background	
Presenting the interviewee background	
The previous warehouse (BEFORE)	10 min
What were the challenges of the manual goods receiving?	
What were the challenges of the manual storing and labeling of products?	
How the tracking of the picking stations level was managed?	
Was it possible to follow the storing speed during the shift?	
Was the capacity of the teams adapted to the amount of work?	
The transition + implementation of technological advancements	10 min
How the selection of technological advancements in the receiving/storing sections was made?	
Who is the supplier of the system logistics? (Is it the same for hardware and software)	
How long did the moving period take?	
How did you handle the period when the two warehouses were operating?	
How close were the tests to the real work conditions?	
The logistics center	**10 min**
How would you qualify the performance of the receiving/storing areas in the first days/weeks?	

Figure 39: Questionnaire 1 (Manager Inbound)

Was the training provided enough for the team to be ready?	
Did the section reach the normal optimized performance yet?	
In case of a negative answer, what are the reasons?	
Overall questions:	**5min**
Are the issues stated in the first block of questions, regarding receiving, storing, and tracking operations are solved? at what rate if not fully?	
As a manager, in brief, what were the 3 main challenges of this transition?	
How would you qualify the warehousing operations in the medical field?	
Wrap up - Closing:	**3min**
Other comments? Questions? Recommendations?	
Thank you for your time	

Figure 40: Questionnaire 1 (Manager Inbound)

A.2 Outbound Manager

Questions	Timing
Introduction	5 min
Thank you for accepting the interview request	
Presenting the project and its goals	
Can the interview be recorded?	
Do you want to be anonymous?	
Presenting the student background	
Presenting the interviewee background	
The previous warehouse (BEFORE)	10 min
What were the challenges of the manual picking?	
What were the challenges of the manual packing?	
How the tracking of the orders shipping was managed?	
Was it possible to follow the picking speed during the shift?	
Was the capacity of the teams adapted to the amount of work?	
What were the main causes of delays for departures? *(Any differences between St Olav and other private clients)*	
The transition + implementation of technological advancements	10 min
How the selection of technological advancements in the Picking/Packing sections was made?	
Who is the supplier of the system logistics? (Is it the same for hardware and software)	
How long was the testing period? did the suppliers of the technologies assist this period?	

Figure 41: Questionnaire 2 (Manager Outbound)

How the tests were conducted? And in what conditions?	
How close were the tests to the real work conditions?	
The logistics center	**10 min**
How would you qualify the performance of the picking/packing department in the first days/weeks?	
Was the testing period and the training provided enough?	
Did the picking/packing section reach the normal optimized performance yet?	
In case of a negative answer, what are the reasons?	
Overall questions:	**5min**
Are the issues stated in the first block of questions, regarding picking, packing, shipping, tracking operations are solved? at what rate if not fully?	
As a manager, in brief, what were the 3 main challenges of this transition?	
How would you qualify the warehousing operations in the medical field?	
Wrap up - Closing:	**3min**
Other comments? Questions? Recommendations?	
Thank you for your time	

Figure 42: Questionnaire 2 (Manager Outbound)

A.3 Warehouse Manager

Questions	Timing
Introduction	5 min
Thank you for accepting the interview request	
Presenting the project and its goals	
Can the interview be recorded?	
Do you want to be anonymous?	
Presenting the student background	
Presenting the interviewee background	
The previous warehouse (BEFORE)	10 min
What were the challenges of the manual processes on the operations?	
How did these factors impact the Warehouse-Suppliers relationship?	
What brought the need of implementing new technologies?	
Can you present the time line of the project?	
What were the main differences in the processes between St.Olav and the other private clients ?	
The transition + implementation of technological advancements	10 min
How the selection of technological advancements in each section was made?	
Who are the suppliers of the system logistics? How were they selected for this project ?	

Figure 43: Questionnaire 3 (Warehouse Manager)

How long was the testing period? How was it structured?	
How the tests were conducted? And in what conditions?	
What was the impact of this transition on the supply chain (suppliers)?	
The logistics center	**10 min**
How would you qualify the performance of the new warehouse in the first days/weeks?	
Was the testing period and the training provided enough?	
Did the new warehouse reach the normal optimized performance yet?	
Overall questions:	**5min**
Are the issues stated in the first block of questions regarding the operations and material flow in the warehouse are solved? at what rate if not fully?	
As a manager, in brief, what were the 3 main challenges of this transition?	
How would you qualify the warehousing operations in the medical field?	
Wrap up - Closing:	**3min**
Other comments? Questions? Recommendations?	
Thank you for your time	

Figure 44: Questionnaire 3 (Warehouse Manager)

B Interviews Consent form

NTNU Interview Consent Form

Interview Consent Form:

Research project title:
"The effects of implementing technological advancements into warehousing operations"

Research investigator: Elmehdi Belabied

The interview will take an average of 40min. We don't anticipate that there are any risks associated with your participation, but you have the right to stop the interview or withdraw from the research at any time.

Thank you for agreeing to be interviewed as part of the above research project.
This consent form is important for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Would you therefore read the accompanying **information sheet** and then sign this for to clarify that you approve the following:

- The interview will be recorded and a transcript will be produced
- You will be sent the transcript and given the opportunity to correct any factual errors
- The transcript of the interview will be limited to **Elmehdi Belabied** and academic colleagues and researchers with whom he might collaborate as a part of the research process
- Any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed.
- The actual recording will be **Immediately destroyed after writing the transcript**
- Any variation of the conditions above will only occur with your further explicit approval

By signing this form, I agree that:

1. I am voluntarily taking part in this project. I understand that I don't have to take part, and I can stop the interview at any time.
2. The transcribed interview or extracts from it may be used as described above
3. I have read the information sheet
4. I don't expect to receive any benefit or payment for my participation
5. I can request a copy of the transcript of my interview and may make edits I feel necessary to ensure the effectiveness of any agreement made about confidentiality

Figure 45: Consent form for the interviews 1.1

6. I have been able to ask questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future

Participant Name: ……

Participant Signature:

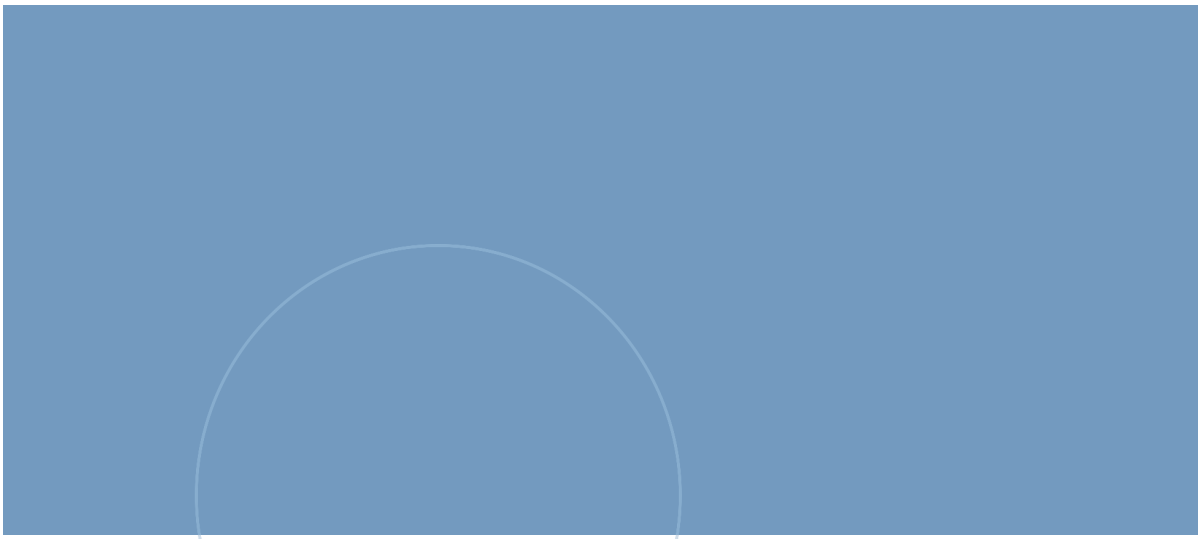
Date:

Researcher Name: **Elmehdi Belabied**

Researcher Signature:

Date:

Figure 46: Consent form for the interviews 1.2



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