Refurbishing of End-of-Life Therapy Systems: Spare Parts Harvesting Process Optimization

Case-Study: Advanced Therapies (AT) business area at Siemens Healthineers Forchheim

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Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Abstract

This work focuses on the Spare Parts Harvesting (SPH) process of medical systems, a process identified as inefficient, characterized by material, information and space wastes and lack of standardized procedures. The goal is to increase its efficiency and productivity resorting to lean methodologies due to their well-documented impact on processes improvement.

A literature review on remanufacturing is presented, and the lean practices successfully implemented in this context are identified. Terminology ambiguity is identified in the literature and in different industrial contexts. A gap is also identified on lean application to spare parts harvesting processes.

A 3-step methodological approach is proposed for process improvement. In the preparation step relevant information is gathered and the process characterized. The execution step concerns process maps development and root-cause analysis to identify challenges in material and information flows, followed by lean practices such as 5S and visual control. The new process is then analysed, and improvements measured in the results confirmation step.

The implemented improvements allowed an average 40% lead-time reduction and an increased number of correctly harvested parts, improving inventory levels and associated costs. The workshop layout was optimized by eliminating motion and space wastes.

Overall it is shown how lean based solutions can impact product recovery processes, increasing efficiency and productivity, and hence increasing competitiveness and economic performance. Environmental and social performance are also improved in the context of circular economy since resource consumption and production activities are reduced, while increasing healthcare access through more affordable refurbished medical systems.

Keywords: spare parts harvesting, remanufacturing, process optimization, lean methodologies, sustainable development.

Resumo

Este trabalho foca o processo de Colheita de Peças Sobressalentes de sistemas médicos, identificado como ineficiente, caracterizado por desperdícios de materiais, informações e espaço e falta de padronização de procedimentos. O objetivo é aumentar a sua eficiência e produtividade recorrendo a metodologias *lean* devido ao seu impacto bem documentado na melhoria de processos.

A literatura sobre remanufatura é revista e as práticas *lean* implementadas com sucesso neste contexto identificadas. Uma ambiguidade terminológica e uma lacuna na aplicação *lean* a processos de colheita de peças sobressalentes são verificadas na literatura.

Uma metodologia em 3 etapas é proposta para a melhoria do processo: na preparação, informações relevantes são reunidas e o processo caracterizado; a execução inclui o mapeamento do processo e análise de causa-raiz para identificar desafios nos fluxos de materiais e informações, seguido da implementação de práticas *lean*, como 5S e controlo visual; o novo processo é depois analisado e as melhorias avaliadas na confirmação dos resultados.

As melhorias implementadas permitiram uma redução média de 40% no *lead-time* e um aumento no número de peças colhidas corretamente, melhorando níveis de inventário e custos associados. O *layout* da oficina foi otimizado, eliminando desperdícios de movimento e espaço.

É mostrado como soluções *lean* podem impactar os processos de recuperação de produtos, aumentando a eficiência e a produtividade e, portanto, aumentando a competitividade e o desempenho económico. O desempenho ambiental e social é também melhorado no contexto da economia circular, uma vez que o consumo de recursos e as atividades produtivas são reduzidos, e o acesso aos cuidados de saúde é melhorado através de sistemas médicos recondicionados mais acessíveis.

Palavras-Chave: colheita de peças sobressalentes, remanufatura, otimização de processos, metodologias *lean*, desenvolvimento sustentável.

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"Always give without remembering and always receive without forgetting."

- Brian Tracy

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List of Abbreviations and Acronyms

GHG	Greenhouse gas
COCIR	European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry
JIRA	Japan Industries Association of Radiological Systems
DITTA	Global Diagnostic Imaging, Healthcare IT and Radiation Therapy Trade Association
NEMA	The National Electrical Manufacturers Association
MITA	Medical Imaging and Technology Alliance, a division of NEMA
GRP	Good Refurbishment Practice
ME	Medical electrical equipment
E.U.	European Union
U.S.A.	United States of America
UN	United Nations
3Rs	Reduce, Reuse, Recycle
MWh	Megawatt hour
CT	Computer Tomography
MI	Molecular Imaging
MR	Magnetic Resonance
XP	X-ray Products
US	Ultrasound
AT	Advanced Therapies
DI	Diagnostic Imaging
LD	Laboratory Diagnostics
ISO	International Organization for Standardization
OHSAS	Occupational Health and Safety Assessment Specification
AG	Aktiengesellschaft
KPIs	Key Performance Indicators
WIP	Work in process
CEO	Chief Executive Officer
C.I.S.	Commonwealth of Independent States
FY	Fiscal year
S.A.	Sociedad anónima
S&H	Siemens & Halske
RGS	Reiniger, Gebbert & Schall
OEM	Original Equipment Manufacturer
RS	Refurbished Systems
WWF	World Wide Fund for Nature

CRs	Contracted Remanufacturers
IRs	Independent Remanufacturers
IBD	Installed Base Development
SCM	Supply Chain Management
CS	Customer Service
BOM	Bill of Material
RO	Returned Orders
SPH	Spare Parts Harvesting
RS HP	Refurbished Systems Harvested Parts
SO	Sourcing department
IVK	Installed Volume of Components
SHS	Siemens Healthineers
EOQ	Economic Order Quantity
5S	Seiri, Seiton, Seiso, Seiketsu, Shitsuke
PRM	Product Recovery Management
R&D	Research & development
CE	Circular Economy
TPS	Toyota Production System
MRP	Material requirements planning
RPA	Rapid Plant Assessment
RCA	Root-cause analysis
PDCA	Plan, Do, Check, Act
DFRem	Design for Remanufacturing
VSM	Visual Stream Mapping
MiniMiFa	Minimum time for information and material flow analysis
SMED	Single Minute Exchange of Die
TPM	Total Productive Maintenance
PFEP	Plan For Every Part
FIFO	First In First Out
OEE	Overall Equipment Effectiveness
SOP	Standard Operating Procedures

1. Introduction

1.1. Contextualization

The world is changing rapidly. The pace of technological change is exponential and according to a study by Kurzweil (2004), at today's rate we will experience 20,000 years of progress in the 21st century alone. From predictions made years ago about the growth of the electronic industry to detailed essays that look back to the "history of technology", there are enough evidences that prove this trend.

In fact, Siemens is responsible for an impressive number of innovations per year: 7,300 in fiscal year 2018 and 3,750 in fiscal year 2019, corresponding to 31-33 inventions per every working day. The company holds around 68,000 patents worldwide and in 2018, with 2,493 patent applications, Siemens ranked first in the European Patent Office's application, surpassing the previous leader Huawei (Siemens AG, 2019).

However, this innovation pace clashes with another very current subject: the impact of greenhouse gas emissions (GHG) on climate change. In fact, the rate of technological change is one of the main driving forces for the increasing global GHG emissions, together with the demographic and socio-economic development (Nakicenovic & Swart, 2000). In 2014, Siemens carbon footprint totalled 2.2 million tons of CO_2 emissions, with electricity accounting for the largest share, followed by heating processes, fleet and other (Siemens, n.d.). Pioneering technologies are part of Siemens' DNA, and innovation can come with a cost to the environment: more waste, resources consumption and pollution.

Nevertheless, in 2015 Siemens announced its plan to cut carbon emissions by 50% by 2020 and to be completely carbon neutral by 2030 – this would make it the first major company worldwide to completely erase its carbon footprint (Siemens AG, 2015). Since the announcement of this initiative, Siemens has already reduced its CO_2 emissions by 41% by establishing energy efficiency projects, leveraging distributed energy systems, reducing fleet emissions and purchasing green energy (Siemens, n.d.).

This dissertation will focus on Siemens Healthineers, one of the three strategic companies inside the Siemens Group. Siemens Healthineers concerns with the healthcare sector and the problem studied in this work fits into Siemens' established goal of reducing its carbon footprint. In the healthcare sector, new improved medical systems are always emerging, and one solution found by Siemens Healthineers to address the dilemma between supplying its customers with the newest of technologies and not continually harming the environment was precisely incorporating a refurbishing process into the supply chain. In 2007, a paper entitled "Good Refurbishment Practice" was published by COCIR[1], establishing "golden rules" to refurbish medical equipment efficiently and safely and which is at the core of the refurbishing process of Siemens Healthineers. Due to positive feedback, COCIR decided to issue an industry standard in June 2009, where refurbishment is defined as a process

[1] COCIR (https://www.cocir.org/) is the European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry, and also a founding member of DITTA, the Global Diagnostic Imaging, Healthcare IT and Radiation Therapy Trade Association (https://www.globalditta.org/).

"*to restore used ME[2] systems into a condition of safety and effectiveness comparable to when new including actions such as repair, rework, update of software/hardware and replacement of worn parts with original parts*" (COCIR, 2009).

In fact, the idea behind a refurbishing process is to put back in the market old, obsolete or defected equipment, which after being carefully inspected, repaired and updated are in conditions to serve their purpose again at an attractive price to the consumer ("*20%-30% reduced cost for healthcare providers, while ensuring safety and high clinical performances*") – as an alternative to completely manufacture a new one with the same attributes (DITTA, 2015).

However, such systems raise questions in the healthcare community, such as the risk it might impose to patients and operators due to a lacking common understanding of what constitutes a good refurbishment practice. Therefore, beyond environmental issues, managing the quality of used medical equipment was also an important driver for the implementation of a refurbishing process in Siemens' supply chain, since in some countries, the import of second-hand medical equipment is banned as a consequence of failing "*to distinguish between high-quality refurbishment to the original manufacturer's specifications and second-hand equipment of undefined quality, with the effect that patients may be denied access to the safe and economical medical equipment they need*" (COCIR, JIRA and MITA, 2009).

The refurbishing process of used medical devices contributes to the three pillars of sustainability – environment, society and economy (DITTA, 2015). On the environmental pillar, refurbishment contributes to prevent waste and to save resources and energy, as it minimizes the need of manufacturing new devices with similar attributes. On the society pillar, as refurbished systems come with a price advantage, it increases healthcare access once it allows for hospitals and healthcare providers with limited budget to substitute their old equipment, consequently increasing the quality of the services provided and safety for patients due to the reduction of the obsolescence of installed equipment. Within the scope of the 17 goals for sustainable development established by the United Nations (UN), goal 3 (good health and well-being), goal 10 (reduced inequalities), goal 12 (responsible consumption and production) and goal 13 (climate action) are particularly targeted (United Nations, n.d.). As for the economical pillar, refurbished systems are growing sales in the market as they are reliable solutions for hospitals and healthcare providers with budgeting constraints. In 2012, the market for pre-owned medical systems has accounted for a global revenue of approximately 480 million euros, with Europe and North America leading the sales of refurbished systems with 74% of the global sales (E.U. 26%; U.S.A. 48%) (DITTA, 2015).

So, it becomes clear the advantages of integrating such process into a company's supply chain: on the one hand to improve the safety and quality of the second-hand medical equipment market and on the other hand the reduction of the carbon footprint by putting into action the 3**R**'s policy – **R**educe, **R**euse and **R**ecycle. According to DITTA, refurbishment contributes to save energy by avoiding the production of new equipment, an estimate of 30MWh for each ton of refurbished medical devices, also reducing CO_2 emissions and the mining of raw materials, decreasing the associated industrial production processes. Refurbishment also contributes to save

[2] Medical Electrical Equipment

scarce resources used in the production of medical devices and helps ensure their supply, such as beryllium or rare earth metals. Minimizing waste by reusing and recycling medical equipment is another advantage associated with refurbishment ("*DITTA estimates that in 2012 around 16,400 tons of used medical devices have been prevented from becoming waste, instead being shipped world-wide for refurbishment and repair*") (DITTA, 2015).

Siemens Healthineers offers the broadest range of refurbished systems for medical imaging and therapy in the industry (Siemens Healthineers, n.d.). The refurbishing process was incorporated into Siemens Healthineers supply chain in 2001 and today an average of 100 Advanced Therapies (AT) ecoline systems (brand name for refurbished systems) are sold every year. Ecoline portfolio includes Computed Tomography (CT), Molecular Imaging (MI), Magnetic Resonance (MR), X-ray Products (XP), Ultrasound (US) and Advanced Therapies (AT) systems. The refurbishment of medical systems is a 5-step Quality Process, as illustrated in **Figure 1**, returning a used equipment to like-new condition with Siemens Proven Excellence Quality stamp, which ensures compliance with Siemens' high-quality standards and the fulfilment of the NEMA/MITA[3][4] standard for refurbishment as well as the ISO 13485, ISO 14001 and OHSAS 18001 standards (Siemens Healthineers, n.d.), (Siemens Healthineers, n.d.). The five steps are: 1) Selection, 2) De-installation, 3) Refurbishment, 4) Installation, and 5) Services. The present work aims at studying the refurbishing process of AT medical systems taking place exclusively in Forchheim (Bavaria, Germany). The Forchheim campus is the headquarters for the Diagnostic Imaging (DI) and Advanced Therapies (AT) business areas (Siemens Healthineers AG, 2019). The process is under the responsibility of the ecoline team of the AT Sourcing department, where this master's dissertation was developed. The third step, Refurbishment, encompasses 6 other processes/operations: Incoming Inspection, Spare Parts Harvesting, Cleaning and Disinfection, Equipment Reprocessing, Reassembly and Final Testing of the refurbished system and Packaging of the final ecoline system.

One of the established objectives for the last fiscal year (October 2019 – October 2020) was to optimize the process of Spare Parts Harvesting, which has large potential for improvement. The business of spare parts has economic relevance for Siemens, as it will be demonstrated in section 3.2., and consists of four main functions: sales and delivery, purchasing, warehousing, and product data management (Suomala, Sievänen, & Paranko, 2002). The authors also characterize two types of spare parts orders: normal orders and emergency orders. A normal order refers to planned major maintenance routines and an emergency order refers to parts requested by customers outside planned maintenance schedules. Therefore, it is possible to realize that managing spare parts inventory is a difficult task to accomplish as it imposes several challenges, such as those highlighted by Dekker, Pinçe, Zuidwijk, & Jalil (2013): parts are often expensive, their demand follows an unpredictable and intermittent behaviour, yet if the company incurs in shortage of stock, the costs can be considerable. Moreover, around 23% of parts become obsolete every year (Cohen, Agrawal, & Agrawal, 2006), which makes it especially difficult to balance inventory levels with obsolescence and stockout costs (Dekker, Pinçe, Zuidwijk, & Jalil, 2013).

[3] NEMA/MITA 1-2015 Good Refurbishment Practices for Medical Imaging Equipment
[4] MITA: Medical Imaging & Technology Alliance – a Division of NEMA: National Electrical Manufacturers Association

Figure 1. Siemens Healthineers "5-step Quality Process"

Source: adapted from Siemens Healthcare GmbH (2019).

On a study by Suomala, Sievänen, & Paranko (2002), the authors mention that the spare parts business is "*assumed to be a very profitable area of business in many cases*" and however lacking reliable confirmation at the time, it was already believed that "*spare parts create one-third of net sales and two-third of profit*". Later, Cohen, Agrawal, & Agrawal (2006) pointed out the economic potential of servicing products, which includes selling spare parts and offering product and customer assistance, by realizing that the aftermarkets of industries such as the automobile, white goods, industrial machinery, and information technology "*have become four to five times larger than the original equipment businesses*".

Therefore, it is easy to understand the importance and relevance of improving the Spare Parts Harvesting process, with such promising economic returns. This will be the subject of study of this master dissertation, and by harnessing synergies and cooperation between the Sourcing department and a master's student, it is meant to find a feasible solution to improve the process.

1.2. Objective

The main goal of the present dissertation is the improvement of the productivity of the Spare Parts Harvesting process (part of the Refurbishment step of the 5-Step Quality process) of the Advanced Therapies (AT) business area. In this particular case, the spare parts retrieved from the medical systems are used to assist customers, for example, in repairs or as part of warranty services. Spare parts can, however, also be incorporated (assembled) in new refurbished systems. In either way, increasing the process efficiency and productivity aims not only to contribute to increase economic competitiveness of the company as the aftersales market is growing, and where spare parts are commercialized, but also contribute to improving circular economy and sustainable development goals by reducing the consumption of resources and production activities (also reducing CO_2 emissions) through the reuse of parts, increasing its useful life, and consequently, the medical system's lifetime. Moreover, from a societal point of view, spare parts process improvement is also expected to contribute to creating more affordable medical systems and repairs, while also increasing the quality and safety of the medical systems by motivating periodic maintenances and therefore avoiding obsolescence of the installed equipment. It can be concluded that by improving the Spare Parts Harvesting process, a contribution to the three pillars of sustainability is provided (environment, society, economy).

To accomplish this goal, the following objectives are defined for the present work:

- Characterize the company (the Siemens Group and Siemens Healthineers), understand its organizational structure and changes that have occurred over the last years, as this is important to define strategies that are in line with the company's vision;
- Characterize the 5-Step Quality process, focusing on the Refurbishment step and in particular the Spare Parts Harvesting process, and analyse the challenges faced;
- Define and analyse concepts relevant for the purpose of this dissertation, and identify suitable methodologies to tackle those challenges by reviewing the available literature on the theme;
- Define the methodological approach to implement reviewed practices, and establish KPIs to measure performance;
- Implement developed solutions and evaluate the achieved results.

1.3. Methodology

A well-thought-out work methodology allows to create a structured, concise and uniform work from start to finish. This dissertation was divided in six main steps (see **Figure 2**). The first step had to do with characterization, that is, contextualize the problem, characterize the company under study and describe in detail the refurbishment of a medical system via the 5-Step Quality process. The second step referred to reviewing the literature so as to gain a deeper academic knowledge on the topic under study, as well to define important concepts used throughout the dissertation and identify lean tools, practices and methodologies used in the context of remanufacturing. The third step comprised the identification of challenges in the Spare Parts Harvesting process, grouped into work procedure and workshop layout, resorting to lean tools reviewed in the literature. The fourth step was where the improvement of the process itself began, starting by improving the work procedure by implementing lean tools, practices and methodologies such as standard operating procedures (SOP), identification of value-adding and non-value-adding operations, eliminating the latter. This was followed by the improvement of the workshop layout (fifth step) in order to allow for a continuous flow, implementing other lean tools, practices and methodologies like 5S and visual control. Supervision and mentorship philosophy was employed during the whole process improvement, otherwise it wouldn't be possible to achieve the desired results, such as process standardization. The fifth lean principle was also took into consideration (pursuit perfection) by continuously monitoring and improving the process. The last step concerned with reviewing the work developed, by reflecting on the main outcomes achieved and suggesting future improvements.

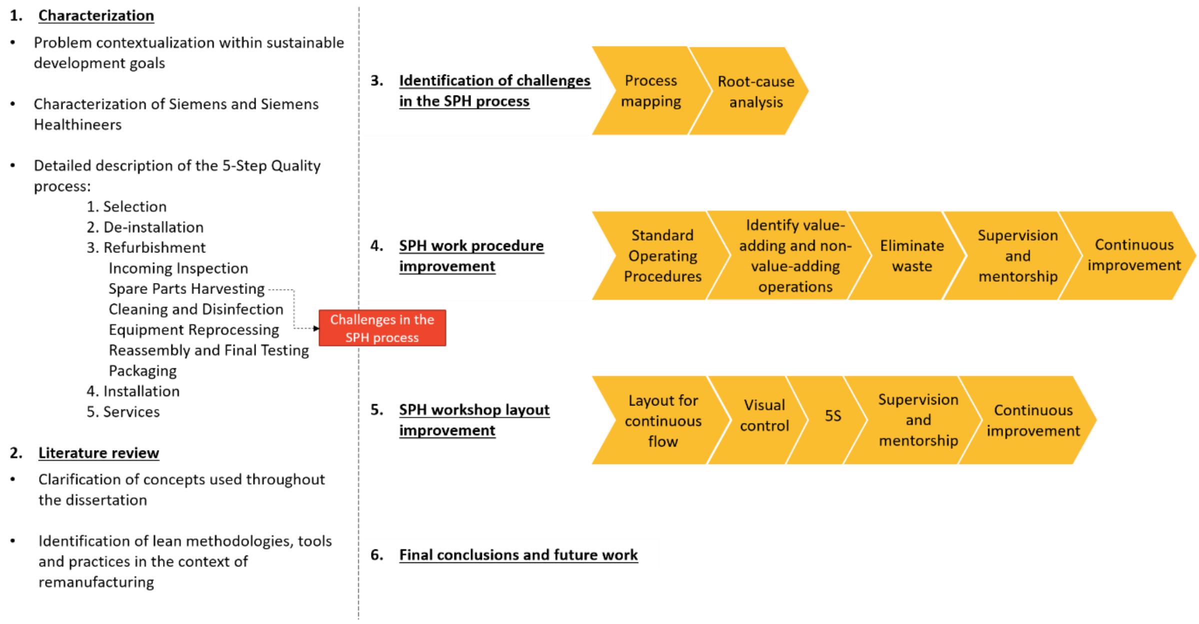

Figure 2. Methodology of work

1.4. Structure

This dissertation is structured in five main chapters, as follows:

CHAPTER 1 – INTRODUCTION. In the first and present chapter, the problem addressed in the present work is introduced, as well as the main expected outcomes of the dissertation, the followed methodology and its structure.

CHAPTER 2 – CASE-STUDY: SIEMENS HEALTHINEERS FORCHHEIM. In the second chapter, an overview of the company is provided, from its foundation to what it is today, and gradually focusing on Siemens Healthineers, one of the three Siemens' strategic companies, within which the problem is addressed and which will be subject of study. Here, the logistic process of refurbishment for end-of-life therapy systems is characterized and a detailed description of the refurbishing process is provided. After a complete understanding of this process, it is possible to identify challenges that will later be addressed by resorting to a lean philosophy.

CHAPTER 3 – LITERATURE REVIEW. In the third chapter, the relevant literature on the problem of product recovery, refurbishing, spare parts business and lean thinking is reviewed, serving as scientific support for this dissertation and promoting further research.

CHAPTER 4 – METHODOLOGICAL APPROACH AND OBTAINED RESULTS. This chapter is divided into four main sections: in the first section, the overall methodological approach followed to improve the Spare Parts Harvesting process is presented; then, the challenges encountered in the process are identified resorting to selected lean tools based on literature review; after which the selected lean tools to effectively improve the process are implemented, first on the work procedure level and then on the workshop layout level; in the fourth section the obtained results are analysed and discussed. It was chosen to present the results in the same chapter as the methodological approach description since, taking into account the nature of the problem and the methodologies employed, it becomes difficult to separate the two contents. This way repetition and redundancies in the document are avoided.

CHAPTER 5 – FINAL CONCLUSIONS AND FUTURE WORK. The last chapter summarizes the developed work along with the main conclusions that can be withdrawn and introduces some ideas for further improving the process.

2. Case-Study: Siemens Healthineers Forchheim

The present chapter aims to introduce and analyse the case-study. It is divided into 3 sections: first, in section 2.1., the Siemens Group and its subsidiary Siemens Healthineers are introduced and characterized. In section 2.2., the refurbishing process of medical systems will be described, and the process of Spare Parts Harvesting detailly explained, which will enable to make a survey of the challenges faced and identify improvement points, which are then summarized in section 2.3.. Finally, in section 2.4., a summary of the chapter will be provided, together with the presentation of the following steps to be developed.

2.1. Company overview

Siemens is an international company with 172 years of history, marked by its innovative character and big achievements in technology. It was the company's resilience to the ever-changing environment along with clever corporate strategies that allow it to assert itself as one of the world's leader in technological solutions and ranking 44 on 2019 Forbes' list for "The World's Most Valuable Brands" (Forbes, 2019).

The history of the company goes back to the year of 1847, when the 30-year-old inventor Werner von Siemens came up with a revolutionary idea to improve the electric telegraph developed years earlier by Charles Wheatstone and William Fothergill Cooke – he created a new type of pointer telegraph that would allow to send messages letter by letter, instead of transmitting it through electrical signals (as it was done by then), a solution that would redefine global communication (Siemens, n.d.). The production of the new device was entrusted to precision mechanist Georg Halske, with whom he founded the "Siemens & Halske Telegraph Construction Company" on October 1, 1847. The company started its operation in Berlin on October 12, 1847 and counted with a team of 10 men. From that day on, the company kept growing and earning international reputation through a series of successful large-scale projects, "*such as the construction of the Indo-European telegraph line and the laying of the first direct transatlantic telegraph cable*". By the time of Werner von Siemens' death, in 1892, the company was generating 20 million marks in sales and employed 6,500 people in nearly 15 countries (Siemens, n.d.).

Siemens as it is known today is the result of a merger of three companies on October 1, 1966: Siemens & Halske AG, Siemens-Schuckertwerke AG (electricity business) and Siemens-Reiniger-Werke AG (healthcare business) (Siemens, n.d.).

Today, the company (Siemens Group) sets presence in more than 200 countries/regions and despite being a global player, its major focus is on the development of the local community. Siemens is an innovative and responsible company that has grown a leading position in the fields of electrification, automation and digitalization. Its businesses include Gas and Power, Smart Infrastructure, Digital Industries, Mobility, Renewable Energies and Healthcare (Siemens, n.d.). The corporate headquarters are in Munich, with registered offices in Munich and Berlin (Siemens, n.d.). Since 2013, the President and Chief Executive Officer of Siemens AG is Joe Kaeser (Siemens, n.d.). Despite 172 years have passed since the foundation of the company, Siemens family still holds the majority share of the company (6.45%) (Siemens, n.d.). It employs approximately 293,000 people around the globe, of which 90% are permanently employed. In fiscal year 2020 (reported at September 30, 2020), revenues of the Siemens Group totalled €57.1 billion, with a net income of €4.2 billion (Siemens AG, 2020). These are some numbers that allow to understand the dimension and impact of the company worldwide and are illustrated in **Table 1**.

Table 1. Siemens general information

Worldwide presence	More than 200 countries/regions
Headquarters	Munich, with registered offices in Munich and Berlin
CEO	Joe Kaeser (2013 – present)
Employees	Approximately 293,000
Revenues[1]	€57,139 million Net income: €4,200 million

1) Refers to FY2020, reported at September 2020.

Source: Siemens AG (2020).

Siemens is an industrial conglomerate which operates in several sectors worldwide. Global megatrends are shaping the future of Siemens markets, such as demographic change, urbanization, digitalization, globalization, and climate change, therefore setting as the long-term growth fields electrification, automation and digitalization (Siemens, 2020). Siemens is organized in three "Operating Companies" and three "Strategic Companies" (see **Figure 3**) (Siemens, n.d.):

Regarding the **Operating Companies** (Siemens, n.d.):

- **Gas and Power** covers the entire energy business;
- **Smart Infrastructures** handles all of the Siemens' infrastructure solutions;
- **Digital Industries** handles the business in industrial digitalization.

As for the **Strategic Companies**, these include the Mobility business and two fully consolidated companies in which Siemens holds a majority stake (Siemens AG, 2018):

- **Siemens Mobility** provides transport solutions;
- **Siemens Gamesa Renewable Energy**, a merger between Siemens AG and former Gamesa Corporación Tecnológica S.A., handles wind power solutions;
- **Siemens Healthineers** covers the healthcare sector and it is the main focus of the present work, as the subject of study is the refurbishment of Siemens medical systems. Therefore, the next section will focus only on Siemens Healthineers.

Figure 3. Siemens organizational structure

Source: Siemens (2020).

Following this introduction, the company **Siemens Healthineers** will be characterized, from the story of its foundation to its current mission and organizational structure, which will allow to understand where exactly in the company (department, section, process and operation) the problem addressed in this dissertation emerges from.

The history of Siemens Healthineers began with the discovery of the X-ray by Wilhelm Conrad Röntgen in November 1895. Despite Werner von Siemens had adventured himself into the medical technology field from an early stage of Siemens & Halske (S&H) foundation, it was not until this discovery that the healthcare business grew significance inside the company. The partners recognized the potential of this new technology and started producing X-ray systems shortly after the discovery, in 1896, becoming one of the sounding names in the sector in the following decades. But they were not alone – at the same time in Erlangen (Bavaria, Germany), "Reiniger, Gebbert & Schall AG" (RGS) was also specializing in the production of X-ray tubes and medical technology and would become S&H biggest competitors in the years to come. However, after World War I, RGS was facing financial difficulties and as an alternative to declaring bankruptcy, they agreed to sell the company's shares to S&H in 1925 and keep the medical technology factory in Erlangen. In 1932, with the global economic crisis of 1929, the idea of merging the two companies was under way and on January 25, 1933, the two officially became one under the name of Siemens-Reiniger-Werke AG. The electromedical equipment production would gradually be relocated from Berlin to Erlangen, where Siemens Healthineers Headquarters can still be found today (Siemens, n.d.). Since February 2015, the CEO is Bernd Montag (Siemens Healthineers, n.d.). Siemens Healthineers alone employs around 54,000 people and in fiscal year 2020 (reported at September 30, 2020), revenues totalled €14,460 million (Siemens Healthineers AG, 2020).

Siemens Healthineers is organized into four business areas, under which the portfolio of medical systems is managed (see **Figure 4**): Diagnostic Imaging (DI), Ultrasound (US), Advanced Therapies (AT) and Laboratory Diagnostics (LD). As the DI business area includes a wide portfolio of distinct imaging systems, it is therefore divided into four business lines: Computer Tomography (CT), Molecular Imaging (MI), Magnetic Resonance (MR), and X-ray Products (XP).

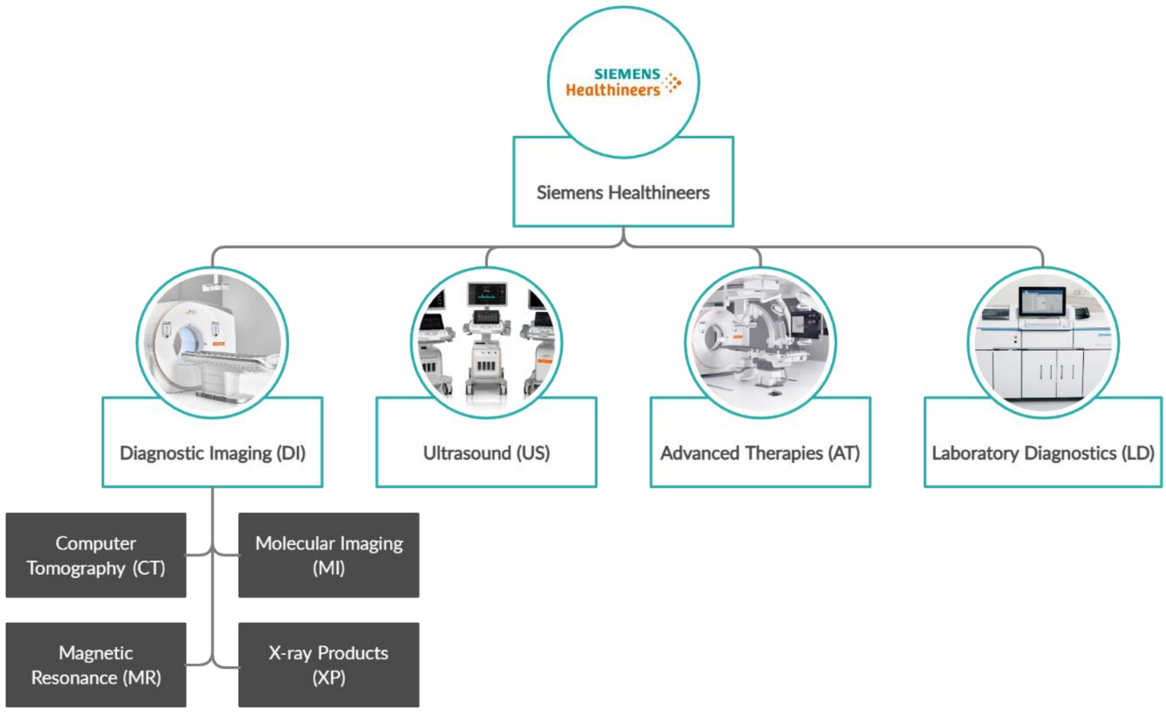

Figure 4. Siemens Healthineers organizational structure

Source: adapted from Siemens Healthcare GmbH (n.d.).

As it is possible to see through **Table 2**, the Imaging segment (refers to the DI and US business areas) presents the highest revenues, followed by Diagnostics (refers to LD business area) and AT.

Table 2. Siemens Healthineers general information

Headquarters	Erlangen		
CEO	Bernd Montag (2015 – present)		
Employees	Approximately 54,300		
Revenues[1]	**TOTAL**	€14,460 million	
	Imaging (DI + US)	€9,090 million	1
	Diagnostics (LD)	€3,924 million	2
	Advanced Therapies (AT)	€1,628 million	3

1) Refers to FY2020, reported at September 2020.

Source: Siemens Healthineers AG (2020).

There are refurbished systems (ecoline systems) for all DI's business lines (CT, MI, MR and XP), US and AT business areas.

Siemens Healthineers holds 18,500 patents globally and has established partnerships with over 90% of the global top 100 healthcare providers. Its positioning is so strong that an estimate of 5 million patients worldwide get in touch with Siemens' medical systems every day, 240,000 every hour (Siemens Healthineers, n.d.).

The present dissertation will be developed in Siemens Healthineers Campus located in Forchheim, within the business area of AT.

2.2. Refurbishing of end-of-life therapy systems: 5-Step Quality Process

After the characterization of Siemens and Siemens Healthineers, it is now time to focus on a major logistic process occurring inside the medical solutions company: the refurbishing process of end-of-life medical systems.

It is now relevant to introduce two concepts: the planned lifetime and effective lifetime of the medical system, as defined in the paper "Good Refurbishment Practice for Medical Imaging Equipment" by COCIR, JIRA and MITA (2009). When the OEM designs and manufactures a medical system, it does so with the purpose for it to be used for a **planned lifetime**, therefore defining maintenance procedures that ensure that the intended levels of safety and performance are preserved after the system is put to service. The planned lifetime usually ends when OEM service, spare parts and components are no longer available for the product. On the other hand, the **effective lifetime** can be limited by different reasons, therefore is usually different from the planned lifetime. COCIR, JIRA and MITA (2009) point out two reasons, described in **Table 3**: functional and economic.

Table 3. Functional and economic reasons for a shortened effective lifetime of medical systems

Functional reasons	Economic reasons
• Poor or lack of maintenance can jeopardize the safety and effectiveness of the medical system; this usually means that the manufacturer's specifications for servicing and maintenance were not fulfilled.	• If a particular costumer wants to replace its old system by a new one, this will reduce the effective lifetime of that system as it will be taken out of service; elevating the replaced system to newer technology is of economic interest for healthcare providers and is the input for the refurbishing process.

Source: COCIR, JIRA and MITA (2009).

That said, refurbishment is taken as a process to maximize the functional and economic life, as illustrated by **Figure 5**.

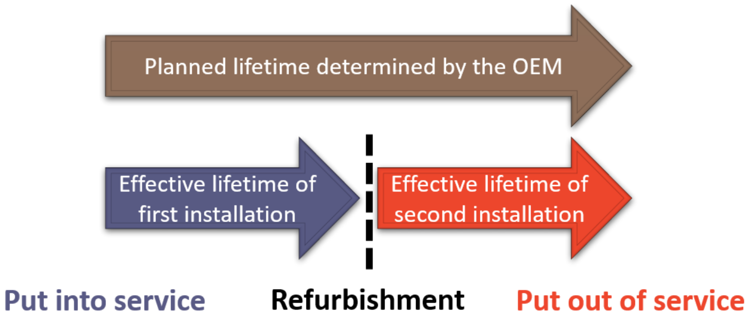

Figure 5. Context of planned lifetime, effective lifetime and refurbishment

Source: adapted from COCIR, JIRA and MITA (2009).

The Refurbished Systems (RS) business line was founded in 2001 based on the market necessity for affordable and up-to-date medical imaging equipment which also met demanding sustainability requirements. With the creation of RS, Siemens Healthineers had accomplished that goal: by incorporating a refurbishing process in its own facilities, it guarantees the quality of the second-hand medical systems at the same time it cuts CO_2 emissions by 20,000 tons and saves money on energy. The integration of such a process proved a success, as a period of continuous growth followed, culminating three years later, in 2004, in the construction of a completely new refurbishing centre in Forchheim, where this dissertation will be developed (Siemens AG, 2013).

By 2016, Siemens Healthineers was leader in the market for refurbished diagnostic imaging systems and presented an annual growth of more than 10%, totalizing to that date 7,500 ecoline systems installed (Siemens Healthcare GmbH, 2016).

Ecoline is synonym of sustainability, and in 2010 Siemens Healthineers went even further by launching the "Proven Excellence Sustainable Impact program" to double the reduction of CO_2 emissions. The program, in cooperation with WWF Indonesia and its NEWtrees Replanting Initiative, committed to plant a tree for every ecoline system sold, with the goal of reforesting 32 hectares of the Indonesian rain forest (Siemens AG, 2013).

As previously seen in **Figure 1**, the refurbishment process of Siemens Healthineers is done via a 5-step Quality Process, which will be detailly described in the following sections.

The refurbishing process itself (third step of the 5-step Quality Process) starts with the reception of the used-systems (referred to as "cores" in the literature by many authors – e.g. Fleischmann, Krikke, Dekker, & Flapper (2000), Sundin (2006), Pawlik, Ijomah, & Corney (2013)) in the refurbishing centre in Forchheim and then undergo several remanufacturing processes such as those in **Figure 6**: inspection, cleaning, disassembly, reprocess, storage, reassembly, and testing (Sundin, 2004). The author also presents a distinction between "reconditioning/refurbishing" and "remanufacturing", based on the works of Ijomah, Bennett, & Pearce (1999) and Lund (1996): refurbishing refers to a product remanufactured to its original specifications and remanufacturing is a generic term to refer to the process of restoring used products to useful life. For the case of Siemens Healthineers ecoline systems, these are in fact refurbished systems as they are remanufactured to its original specifications by the OEM. There are three types of remanufacturers: the original equipment remanufacturers (equivalent to the OEM), the contracted remanufacturers (CRs), and the independent remanufacturers (IRs): OEM refers to manufacturers that perform the remanufacturing of their own products (like Siemens Healthineers), CRs are contracted by the OEM to perform remanufacturing processes, and IRs work independently from the manufacturers, often as competitors in the same market (Östlin, Sundin, & Björkman, 2008).

Figure 6. The generic remanufacturing process

Source: adapted from Sundin (2004).

The remanufactured product incorporates both old and new parts, as referred by Haynsworth & Lyons (1987): "*the new product is reassembled from both old and, where necessary, new parts to produce a unit fully equivalent – and sometimes superior – in performance and expected lifetime to the original new product*", which in the case of AT systems the proportion is about 80/20 (80% new parts, 20% old parts; for other ecoline systems of the DI business area, the proportion is about 50/50).

The focus of this dissertation will be the Spare Parts Harvesting process, inside the third step (Refurbishment) of the 5-step Quality Process. As mentioned before, managing the inventory of spare parts presents several challenges and forecasting their demand is especially difficult (this will be explored further ahead in section 3.2.2.). As using only historical data is not sufficient, the Installed Base Development (IBD) business line plays a significant role. It becomes relevant to, therefore, introduce the concept of installed base. Dekker, Pinçe, Zuidwijk, & Jalil (2013) have elaborated the definition of installed base as "the whole set of systems/products a company has sold and which are still in use" provided by the Longman Business English Dictionary (New Edition) (2007), to "*the whole set of systems/products for which an organization provides after sales services*", pointing out that the OEM does not need to be the organization providing after sales services (however, this is the case for Siemens Healthineers).

That said, the four main intervenients in the refurbishment of AT medical systems are the AT Sourcing department (mainly the ecoline team), the Supply Chain Management (SCM) Coordinator for all the business areas, the IBD business line and the Customer Service (CS) department. In the following sections, the 5-step Quality Process will be detailly explained.

2.2.1. Selection

The selection process is the first step of the 5-step Quality Process to completely refurbish a used medical system (see **Figure 1**). The selection process concerns with the check-up of the medical system, such as its condition, service history, performance and technology level (Siemens Healthcare GmbH, 2019). This check-up is done via the system's record in Siemens database, where it is possible to check all technical details from any system, since its manufacturing date to all components constituting the system (its bill of material – BOM) and upgrades and maintenances suffered over the years. According to this check-up, Siemens Healthineers can decide whether to buy its own system back or not.

Any Siemens medical system is immediately a candidate for refurbishment as there are interests behind it, such as preventing competitors from getting access to Siemens Healthineers know-how and expertise by exploring technologies used in the system (brand protection), and economic interests due to the value of materials incorporated in medical systems, which they don't need to rebuy, but also to secure spare parts supply and warranty (Seitz, 2007).

The selection process involves two departments: the IBD and the respective Sourcing department of each business area, depending on the system incoming for refurbishment. For this case-study, it is the AT Sourcing department.

The selection process only applies to customers who are in possession of a Siemens medical system. When these customers want to buy a new system, Siemens proposes to buy their old system back and in return they are granted a discount in the next purchase, whether in an ecoline system (refurbished system) or in a new system. If the customer is not interested in acquiring a new system and simply wants to get rid of the old system, he will still receive some money for it. The buy-back process is how Siemens recovers used systems for refurbishment (it is the input to the refurbishing process) and it follows two categories: the Elevate R and the Elevate O.

- The Elevate R (stands for **R**eplacement/**R**efurbishing) means that the used system is in fairly good condition and it is suitable for refurbishment – in this case, the customer receives a discount on the next purchase.
- The Elevate O (stands for **O**utdated) means that the used system is very old and it would be too costly to refurbish it. In this case, the customer receives a discount on the next purchase, but it goes directly to scrap (it is scrapped locally).
- Straight buy-back: it has no relation to the purchase of a new system – a customer is selling a system, and based on the conditions, Siemens chooses to buy it back or not.

At this stage, this system check-up is done exclusively via a database, remotely. The customer has to specify the system he owns and through this information it is possible to find the system in Siemens' database. The visual check-up of the system occurs later in the Refurbishment step.

Then, if the customer is interested in buying a new system (whether ecoline or new-new), he has the possibility to configurate it to his own preferences. The price for the personalized system is matched through a "price-book", a pricing table that works exactly like a car configurator.

2.2.2. De-installation

The de-installation process is the second step of the "5-step Quality Process" (see **Figure 1**). Here, the medical system is de-installed and taken from its current location to Siemens Healthineers facilities located in Forchheim (Bavaria, Germany) for a visual check-up.

The de-installation is coordinated between the responsible of the returned orders (RO) in the Supply Chain Management department, the authorized forwarding agent and the project manager representing the customer: it is necessary to agree on the date for the de-installation and prepare transportation frames. The de-installation of the system itself is done by a Siemens Healthineers' logistic partner, usually Simon Hegele, with whom Siemens has already a long partnership dating from 2012 (Logistik Heute, 2012). Siemens Healthineers is responsible for training Simon Hegele workers, in order to guarantee professional execution and non-destructive de-installation. To assure that the system is not damaged during the transportation, it will be dismantled in its several parts for easier and safer transportation. For clarity, the terminology used for the constitution of a medical system is: system, to refer to the equipment fully assembled, and part to refer to any component used in the construction of the system. Therefore, a part might either refer to a big part, such as a C-arm of an AT system or a generator, or to a smaller part, such as a circuit board inside a generator. Big parts are usually identified as main parts as they are almost always reused in ecoline systems (except if extremely damaged). For example, a table (**Figure 7**) or a C-arm (**Figure 8**) are main parts and these usually constitute the 20% of old parts in an AT ecoline system (recalling the 80/20 proportion of new/old parts in AT ecoline systems).

Figure 7. Table of an AT system ("main part")

Figure 8. C-arms of an AT system ("main part")

Spare parts are smaller parts usually inside these main parts. For example, the generators in **Figure 9** are main parts, and inside them can be found spare parts, such as a circuit board as shown in **Figure 10**.

Figure 9. Generators of an AT system ("main parts")

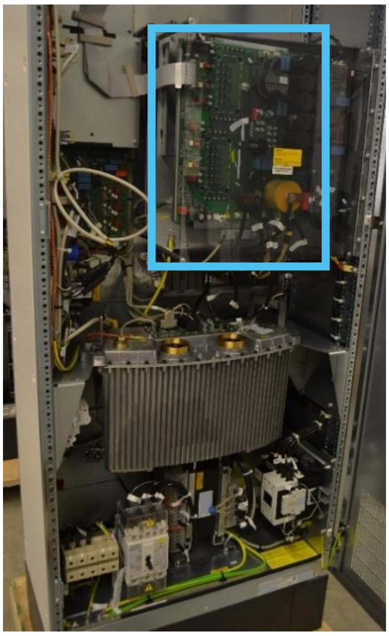

Figure 10. Spare part inside a generator (highlighted in blue)

When de-installing the medical system, these different main parts will be disassembled and packed separately for shipping to Forchheim.

2.2.3. Refurbishment

Refurbishment is the third step of the "5-step Quality Process" (see **Figure 1**) and the core of an ecoline process, since it is where the system is reprocessed in order to start a new lifecycle: it will be cleaned inside out, the outside of the equipment repainted or replaced, damaged and worn parts replaced with original Siemens spare parts, the software updated to the latest applicable version, and the system configurated according to customer's specifications. This is a complex step as it incorporates 6 other processes/operations (as it was shown in section 1.1., **Figure 1**): Incoming Inspection, Spare Parts Harvesting, Cleaning and Disinfection, Equipment Reprocessing, Reassembly and Final Testing, and Packaging. Similarly to what happens in the de-installation phase, many of this processes/operations are also performed by Simon Hegele (the logistics partner). **Table 4** provides an overview of the tasks carried out in the Refurbishment step, identifying the company performing each one, as well as the location where it takes place. Most of them takes place at the Simon Hegele refurbishing centre (inside Siemens Healthineers Forchheim campus), but the "technical refurbishment", which refers to the equipment reprocessing (update software and replace parts), takes place at the OEM.

Table 4. Location and company performing each task of the refurbishment process

	Location			Performed by	
Process	**Simon Hegele** refurbishing centre Forchheim	**Siemens Healthineers** Forchheim	**Original Equipment Manufacturer (OEM)**	**Simon Hegele**	**Siemens Healthineers**
Incoming inspection	X				X
Spare parts harvesting	X			X	
Cleaning and disinfection	X			X	
Equipment reprocessing			X		
Reassembly of the ecoline system and final testing		X			X
Packaging of the finished refurbished system		X		X	

Nevertheless, even if the process/operation is performed by Simon Hegele in its own facility, Siemens Healthineers still has the total control of the process and decision power. That said, Siemens Healthineers is responsible for providing the adequate training to Simon Hegele workers and decide on how it wants things done.

At the end of this step, after going through all the following 6 processes/operations, the used system shall look like new and ready to serve its purpose again.

- **<u>Incoming inspection</u>**

When Siemens buys back its own second-hand medical system, the system is disassembled on site and the several parts of the system are received in the Simon Hegele refurbishing centre located in Forchheim. Then the first step of the refurbishment process takes place, the incoming inspection, where the parts will be carefully observed by a technical engineer (visual check-up) who decides upon their condition which ones are good for reuse in new ecoline systems and which are not, also sorting the parts containing spare parts, separating them for the rest of the units. As mentioned before, usually the parts for refurbishment are the main parts like a table or a C-arm, and all the other parts either go to the spare parts harvesting or to scrap.

This incoming inspection is made with the support of 3 important lists:

Table 5. Lists used to support the incoming inspection process

1. TD list	2. IVK list	3. Requirements list
This list is issued when a customer buys a medical system from Siemens for the first time and identifies all parts used in that system (broadly speaking, its Bill of Material – BOM).	IVK stands for installed volume of components and has registered all updates and maintenances done in that same system over the years. This list identifies special parts (IVK parts) that can be used all over the world and it's the responsibility of each country's Customer Service (CS) to update the status of each IVK part (for example, when a part is replaced due to damage, it must be updated in the SAP software).	This list is a mix of the previous 2 as it contains all part-numbers present in the system, as well as the ones that are IVK parts. It also identifies the parts from that system that can be used for ecoline systems. This is made automatically through a system flowchart that by analysing the record of that system can "guess" which parts are in good condition to reuse or not.

Having said that, the parts arrive in Forchheim and are taken to a receiving area where all electrical cables are removed. Then, the technical engineer must visually check the parts identified as good for refurbishment in the third list and decide if they are in fact good to reuse in ecoline systems – if yes, the part receives a yellow label identifying it should go to the cleaning and disinfection phase; if not, i.e. if the price of refurbishment is higher than the price of manufacturing that part, it will enter the Spare Parts Harvesting process – this is illustrated in **Figure 11**. In the latter case, the parts are put aside in trolleys (small parts) and pallets (bigger parts, like a generator) so they can later be picked up. In the Spare Parts Harvesting process, the parts received will be thoroughly looked at and if they are or contain a spare part inside, it will be disassembled and stored in a spare parts warehouse. All the remaining parts are then recycled (this process will be better explained in the next section).

After the visual check-up, the technical engineer must create a system protocol with all technical aspects of that system in SAP. In this protocol, some questions must be answered, such as the origin of the equipment (this is relevant because equipment coming from the E.U. can only be sold in the E.U. and the same for equipment coming from outside the E.U.). The protocol also identifies parts that might be missing or damaged (during transportation for example), so that a refund can be imputed to the customer or to the logistic partner handling the transportation. The protocol is a technical file that also specifies the operations needed to refurbish that part. This is useful because the technical refurbishment of the part (equipment reprocessing) is not done in Forchheim but at the OEM – this will be explained further ahead in the equipment reprocessing section – and this technical file let the OEM know how to deal with the parts (what needs to be replaced, what needs to be newly-manufactured, etc.).

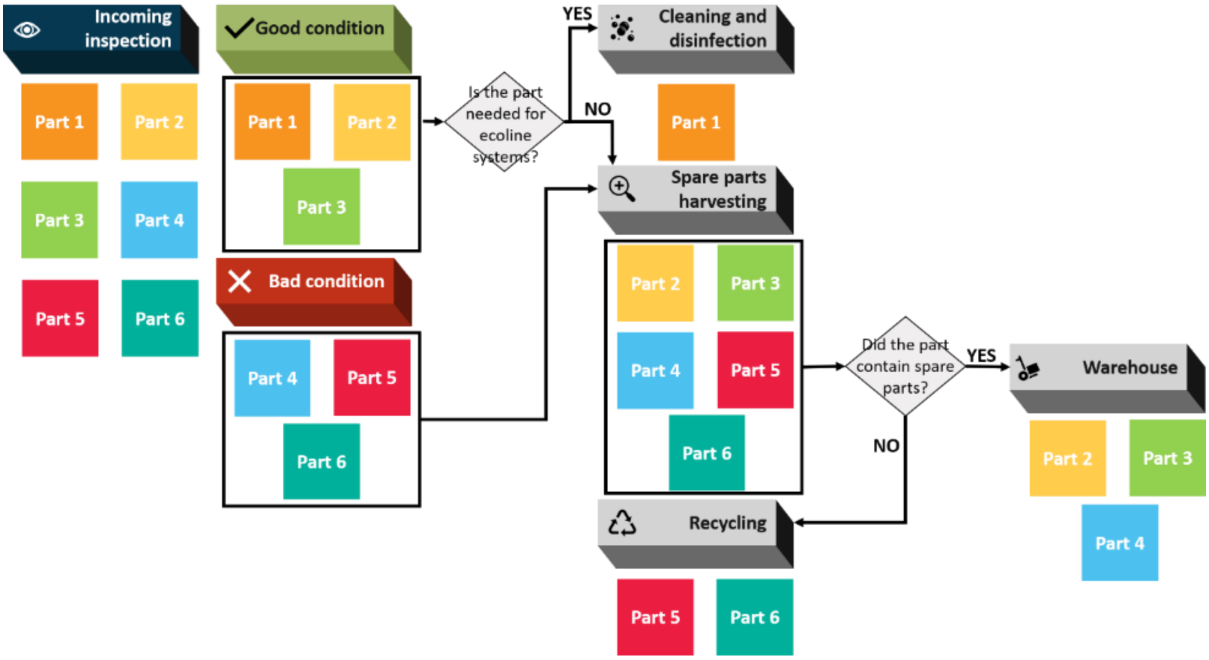

Figure 11. Representation of the visual check-up of the system and assortment of parts in the incoming inspection

➢ Spare Parts Harvesting

Spare parts are parts maintained by the Customer Service (CS) department so they can provide aftersales assistance to customers in case the need arises, that is, if a part of a customer's medical system gets damaged and needs replacement. For new systems, Siemens Healthineers warranty program ensures spare parts availability for a minimum of 10 years; for ecoline systems, 5 years.

There are two possibilities for ensuring spare parts inventory: by buying spare parts from vendors (the most usual), or by harvesting parts from used systems for refurbishment. This last case is the one addressed in this master thesis. Nevertheless, an explanation of the first case is also provided.

There are 3 main CS:

- CS Erlangen (Germany) is the main one as it is located at Siemens Healthineers headquarters, and is responsible for the European spare parts vendors. Moreover, it is also the only CS responsible for a Spare Parts Harvesting (SPH) process, which means the orders for harvesting parts is the exclusive responsibility of CS Erlangen and the SPH only takes place in the Forchheim facilities;
- CS Shanghai (People's Republic of China) takes over Chinese spare parts vendors;
- CS Cary (U.S.A.) is responsible for North American spare parts vendors.

These 3 CS are responsible for maintaining and ensuring the supply of spare parts to customers all over the world, with the support of 3 spare parts warehouses:

- Neu-Isenburg warehouse (Germany) ensures the supply of spare parts to the European customers;
- Memphis warehouse (U.S.A.) covers the North American market;

- Singapore warehouse (Singapore) supplies the Asian customers.

CS forecasts the demand for spare parts on a weekly-basis and places orders to suppliers to satisfy the optimal inventory levels: the order quantity is calculated by comparing the optimal inventory with the current stock. On the other hand, the forecast is done by estimating the re-order point having in consideration the product life cycle and is based on the EOQ (economic order quantity) plus a buffer. When a part is replaced from a system in the field, it is not immediately scrapped (except if extremely damaged) but is instead stored in the "defect" warehouses (identified as **2081**) as a defect part. This defect part then goes to the original supplier for repair and returns to the "new spare parts" warehouses (identified as **2050**) as a new spare part. This is of economic relevance for Siemens Healthineers as the price of repair is often cheaper than buying a new part.

It might happen that a supplier announces that he will stop the production of a certain part and, therefore, CS must proceed to the "last buy" order process, this means, it needs to calculate a last order quantity in order to ensure the supply of that part to all active systems around the world in their remaining service time. So, what happens if something went wrong in the calculations or the demand for that part has shifted? This introduces the next available option for ensuring spare parts inventory: the Spare Parts Harvesting (SPH) process. This process, beyond the sustainable and economic factors already explored, it is also a source of parts that might no longer be available at the suppliers.

As mentioned, this process (SPH process) only takes place at Siemens Healthineers Forchheim and is of the entire responsibility of each of the business lines **in this campus** and the **CS Erlangen**. All the parts harvested from the used systems incoming to Forchheim are defect parts, therefore are stored in a 2081 warehouse also in Forchheim, and as it happens to the ones from field, these too must be repaired before being stored in the 2050 warehouse in Neu-Isenburg as a new spare part.

For simplicity, the process is going to be divided into two: **(A)** the booking of parts from Forchheim to CS Erlangen, **(B)** the SPH itself.

(A)

The booking of parts from the warehouse in Forchheim is rather a simple process: every week, the CS Erlangen sends a list to the Sourcing department (SO) of the several business areas in Forchheim, requesting parts from the **2081** warehouse (the "defect" warehouse, i.e., the warehouse storing the harvested parts from the used systems for refurbishment). This list is the result of the weekly demand analysis in order to ensure the optimal inventory level at the **2050** warehouse in Neu-Isenburg (the "new" spare parts warehouse). Therefore, it takes into account the time it needs for the "defect" parts to go to the supplier for repair and to be shipped to the warehouse in Neu-Isenburg, maintaining the desired inventory levels. The weekly demand analysis is done through a master file, entitled the **data pool file**.

The data pool is an extensive excel file created by CS where all relevant information to manage and control spare parts inventory is, including all the calculations for the demand forecast and for the optimal inventory levels, also providing the information for the current need of stock for harvested parts in the 2081 warehouse. This is the input to create and issue the list to every SO, specifying which parts should be harvested and in which quantity, to meet the desired 2050 inventory levels. **Table 6** provides an example of this data pool file, and **Table 7** an example of the resulting list sent to SO. This is a very important file and will be mentioned several times in the following developments.

Table 6. Data pool excel file example

Material no.	Description	2050_Current stock	2050_Optimal stock	2050_Difference current-optimal	2050_Avg. monthly use	2050_If demand, transfer qty per week	2050_Current months until demand or "DEMAND" if immediate demand	Ecoline systems yearly demand	Ecoline systems max inventory	Ecoline inventory control	Stock 2081	2050 Quantity part transfer current week - DEFECT
231	Panel	20.75	25	-4.25	1.83	4.25	DEMAND	54	51	Ok	1	1
243	CCR2 board	8.73	1.5	7.23	0.31	0	169.32	1	0	Excess inventory	1	0
578	EKG	32.6	50.4	-17.8	23	16.8	DEMAND	252	202	Ok	5	1
962	Stand	12.55	22.4	-9.85	9.11	8.85	DEMAND	76	76	Ok	31	4

Table 7. Example of the list sent to SO requesting "defected" parts

Part no.	Business line	Qty
231	AT	1
578	AT	1
962	AT	4

Note: the input to this list is the column "2050 Quantity part transfer current week – DEFECT" from **Table 6**.

The overview of this process **(A)** is illustrated in **Figure 12**.

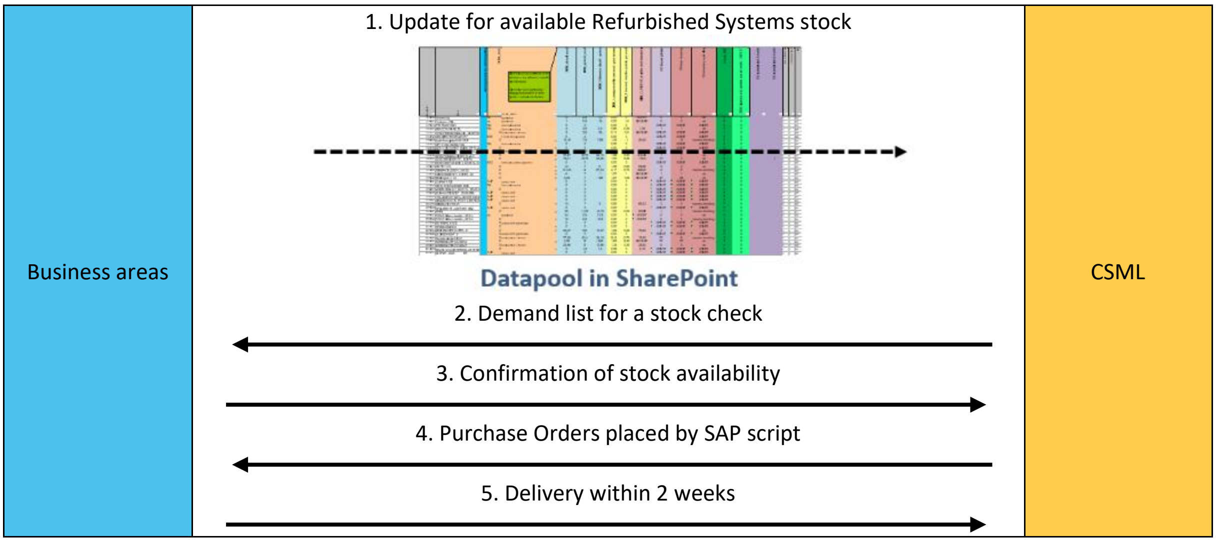

Figure 12. Overview of the booking of parts from Forchheim to Erlangen

(B)

When the incoming inspection is finished, the parts put aside are collected by a Simon Hegele worker and taken to the Spare Parts Harvesting, together with the requirements list. The process of Spare Parts Harvesting can now begin.

To simplify, the process is going to be described in 3 phases: the first phase concerns with searching for the parts, the second phase with disassembly of parts for stock and scrapping the unneeded parts, and the third phase concerns with cleaning the workshop. This part of the process was carefully observed to actually see how the process is carried out. This was very important to identify difficulties faced by the worker, inefficiencies (such as time-consuming tasks and space disorganization) and clearly understand the process. All perceived challenges/problems are enumerated and highlighted throughout points i. Searching for the parts, ii. Disassembly of parts needed for stock and destruction of the remaining, and iii. Cleaning the workshop.

i. Searching for the parts

To begin with, the worker opens an excel file (the spare parts list) which identifies all spare parts by part-number. The worker then searches for all Siemens labels present on the system received, marking the correspondent part-number with a "✓" in the requirements list to indicate that he has been through that part. If a part-number is in a grey line in this requirements list, it means it is an IVK part and most likely is an important part for spare parts. If it is not in a grey line, the worker must check on the excel file (spare parts list) if it is a part to save or to scrap – the parts to save are clearly identified in green and with the terminology "RS HP" (Refurbished Systems Harvested Parts); the parts to scrap come with the description "to discard" (see **Table 9**).

Here it was already possible to identify a problem (**challenge 1**): this spare part list contains 2,011 part-numbers and according to CS and SO departments, this list has not been updated in, at least, the last 4 years. This means the list is that long because every once in a while, new parts join the list (introduced by CS when there's demand for parts until then not in the list, e.g. because of a system that is recent and only now is starting to be refurbished for the first time) but the parts that are no longer being harvested continue there (e.g. the ones that have expired the 5 years warranty), increasing the size of the list to thousands of items – from those 2,011 part-numbers, currently only 146 are identified as parts to save for inventory. The spare parts list has been identified as a big challenge for improvement, as its content involves at least 3 distinct departments – the CS, the SO and the IBD.

Another identified problem by this stage was that the requirements list is not 100% suitable for the SPH process (**challenge 2**) – this list comes from the incoming inspection to identify, mainly, the parts to refurbish and to check if the whole system was received in the refurbishing centre or if some part is missing. Therefore, the parts relevant to refurbish are marked in a column with the header "in the requirements list", the parts that are missing in a column "not present" (so, they were not received in Forchheim), and those **not relevant for the incoming inspection** in a column "not relevant" – see **Table 8** for an example. It might happen in the SPH that a component is identified as "not relevant" but the worker knows they sometimes need it, from experience, as for example the "circuit board" in **Table 8**. When he checks the spare parts list (the excel file) for that part-number, he can confirm that is a part to save, as it is marked in green with RS HP (**Table 9** illustrates this situation). It is therefore possible to conclude that the list can be improved for the SPH process, as it can cause confusion to the worker, especially to a new worker not familiarized with the process and therefore not used to know which parts are usually spare parts.

Table 8. Example of the third list, requirements list.

In the requirements list	In the TD list	Part no.	Serial no.	Description	Not relevant	Present	Not present	Comment
		123[1]	123ABC	Software	X			To scrap
X		456[1]	456DEF	Table		X		To refurbish
		789[2]	789GHI	Detector		X		
	X	112[2]	112JKL	Circuit board	X			
	X	113[1]	113MNO	Protection			X	

1) The worker does not need to search for this part no. on the excel file to confirm if they are spare parts or not as they are identified that one has already gone to scrap, the other went to refurbishing and the other was not received in Forchheim.

2) The worker needs to check if it is a part needed for spare parts: the IVK part must likely is, and the other marked with "not relevant" might be relevant for spare parts (see **Table 9**).

After finishing checking all labels, the worker must search in the spare parts list for all the part-numbers he signalized with "✓" in the requirements list, marking them with "X" so the list can later be filtered, and fulfils for each its serial number and revision number, even if it is clearly identified that it is a part to scrap. For example, it was observed the harvesting of a monoplane system (so, not a complex system) and it contained **68 part-numbers** – from these, only **6** were RS HP, and from these only **4** were **actually needed for inventory**. Nevertheless, he wrote down all 68 serial and revision numbers. It is not clear why he does this because the list is only sent to SO department and the first thing it is done when the list is opened is to filter it by the cells containing RS HP, which means all the other parts he wasted time filling are not even looked at. It needs to be cleared up the reasons why he has to fill in these parts to scrap (**challenge 3**).

Table 9. Example of the spare parts list fulfilled in the SPH process

	The worker must search for all part no. on Siemens' labels in the system and then look for them in the excel file ↓	After finding them, he must **fulfil** the serial no. and the revision no. ↓	↓	RS HP identifies parts needed for spare parts; "To discard" identifies parts currently not needed for spare parts. ↓
	Part no.	**Serial no.**	**Revision**	**Handling**
X	789[2]	789GHI	3	RS HP
X	112[2]	112JKL	2	RS HP
X	123	123ABC	3	To discard
X	789	789GHI	0	To discard
X	123	123ABC	3	To discard

2) Refers to the part no. present in **Table 8** (cross checking). As both are identified with RS HP, then both are parts to save.

After filling the excel file, he then sends it to SO so they can check from those RS HP parts, which ones are actually needed. As mentioned, the list is first filtered and then the stock of each of those RS HP parts are checked in SAP, which also shows when the parts were booked (needed) and quantities sent from the warehouse to CS; upon this quantity check it is decided if it is necessary to keep those parts or not.

It was also observed how the Siemens Healthineers worker responsible for receiving the excel file carries out this particular process and another problem was immediately found (**challenge 4**): he has no reference for the maximum and minimum quantities of parts necessary to keep in stock in the 2081 warehouse. This is obviously a big issue because the demand for spare parts is very volatile and CS together with IBD have developed complex forecasting models which are completely ignored at this stage. He decides "yes, keep it" or "no, scrap it" based on his intuition. It was confirmed that no one in the AT Sourcing department works with the data pool file mentioned before, which is a big mistake since all relevant information is there (including the min-max references for spare parts volume). Therefore, when improving the spare parts list, the data pool must be considered.

ii. <u>Disassembly of parts needed for stock and destruction of the remaining</u>

After the search, the worker must now disassemble the identified needed parts, i.e. the ones identified by RS HP on the spare parts list. In the example above (**Table 9**), the circuit board must be taken out (disassembled) of a metal cabinet, among other parts. The ones that he doesn't need, he must destroy the Siemens label present on that part in order to protect Siemens intellectual property when it is discarded. Motors containing oil and batteries must also be separated for recycling.

iii. <u>Cleaning the workshop</u>

Now that the critical tasks are done, the worker must clean the workshop. The system comes in pallets, which sometimes are in bad condition and leave wood traces behind. Moreover, the parts are often dirty and dusty, so it is important to clean everything after each system. The worker must also take the parts to scrap to a recycling area, the pallets to another area, and gather all spare parts in a trolley until he receives the confirmation from SO which parts are actually needed from the parts he saved. This confirmation arrives via a second e-mail and then he can finally proceed to the storage of the actually needed parts in the 2081 warehouse – but let's not forget that meanwhile he already wasted time disassembling all RS HP parts and lost space by having to keep them. It is easy to understand that these exchanges of e-mails are very inefficient (**challenge 5**), as they represent a non-value-added processing activity, besides creating waste of time (disassembling the parts and waiting for the reply on which are really important), space and information. It is also possible to assert that at the moment, due to the fact that the spare parts list has not been updated in years, certainly there are spare parts which are needed for stock but are not disassembled because they are not on the list. Therefore, spare parts are lost along the refurbishing process (**challenge 6**).

After receiving the second e-mail, the worker must wrap the **actually needed** parts and issue a label to the spare parts warehouse. The spare parts are now temporarily stored in a cart, waiting for it to become full so it can be later taken to the 2081 warehouse.

A problem that could also be identified throughout the process was movement inefficiencies due to poor space organization (**challenge 7**). The main parts come in pallets, usually 6 to 8 per monoplane system and 8 to 12 per biplane system, and the smaller parts in trolleys, usually 1 or 2 per monoplane system and 2 or 3 per biplane system. There are 2 workers harvesting parts for AT systems in an area of 100 m^2, so there are usually 12-24 pallets and 3-5 material trolleys waiting to be harvested. As it is not possible to place all the pallets and material trolleys at the same time inside the room, the workers bring in and take out pallets as they complete them (they are waiting in line outside the room). The problem is they do not have a predefined space to leave them, so they leave the pallets and the material trolleys scattered randomly. Therefore, when the worker needs to move a pallet or trolley (first to look for the Siemens' labels and then to take it out so as to bring a new pallet or material trolley in), it was often observed that he first has to move the ones in the way – the photos in **Figure 13**, **Figure 14**, **Figure 15** and **Figure 16** illustrate this problem. As it is possible to observe, there is lack of space between the pallets and trolleys, so the worker continually has to move the pallet/trolley in order to have space to look for the Siemens' labels. With a layout reorganization, wastes of motion and waiting times (e.g., searching for the tools) can be reduced or eliminated.

However, the major identified problem is the lack of standardization across the whole process, both in the procedure and in the workshop layout (**challenge 8**). There are no guidelines to support worker's operations, so they just adapt to the situation the best way they can and perform the job the best way they know.

Figure 13. Pallets and material trolleys left inside the SPH workshop

Figure 14. Generators one after the other, with no space in between

Figure 15. Overview of the pallets and material trolleys position

Figure 16. Overview of the SPH workshop

For clarity, the overall process of SPH is illustrated in **Figure 17**.

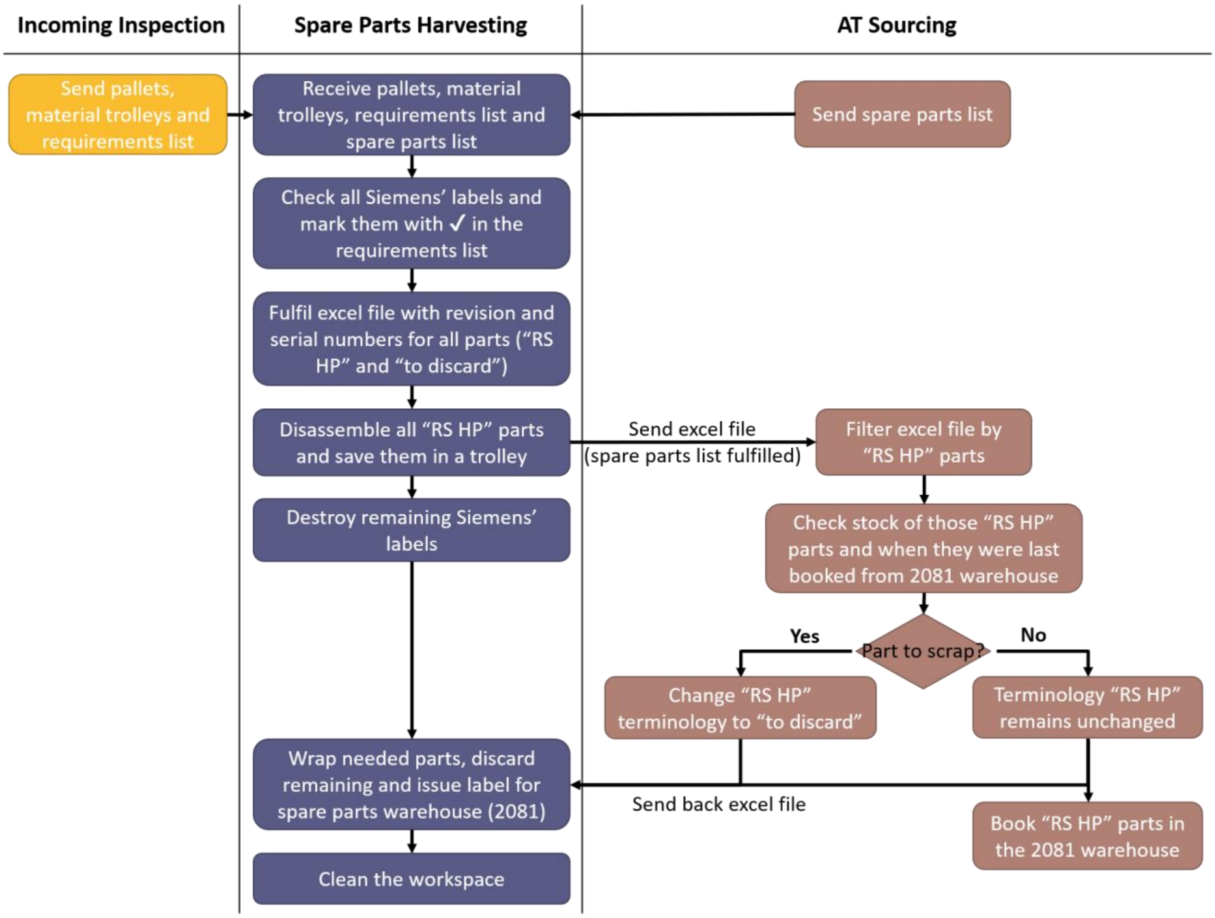

Figure 17. Spare Parts Harvesting process overview

The overall lead-time for the SPH process is between **8 hours for a monoplane system** (that is, simpler systems with only one C-arm), and **12 hours for a biplane system** (more complex systems with two C-arms). These lead-times are the standard times for completing one system, according to the Simon Hegele workers. The goal is to reduce the lead-time of the process by tackling the identified challenges.

- **<u>Cleaning and disinfection</u>**

After the administrative job described in the incoming inspection, Simon Hegele workers can collect the parts identified with the yellow label and take it to the cleaning and disinfection area, where they are also painted. Only after painting can the respective part be shipped to the OEM for refurbishment.

When this cleaning process is completed, it receives a new green label identifying the part is disinfected.

- **<u>Equipment reprocessing at the OEM</u>**

As mentioned, the technical refurbishment takes place at the respective OEM.

There, they are reprocessed according to the technical protocol elaborated in Forchheim. The technical refurbishment includes upgrading the system to the latest applicable software version, replace old parts by newly manufactured ones, and customize it according to customer's specifications. The system is thoroughly tested and when finished, it is shipped back to Forchheim. This is the longest process of the third step – between **1 to 2**

weeks – and, therefore, representing the constraint in terms of lead-time delivery of ecoline systems to customers.

- **Reassembly of the ecoline system and final testing**

After the equipment reprocessing at the OEM, the ecoline system is almost finished, but it still needs to go to an assembly line to gather all the refurbished and new parts together, bringing a new system to life – the ecoline system. Then, it must pass a final testing stage and if all is ok, the system is redirected to the packaging area by Simon Hegele workers.

- **Packaging of the finished refurbished system**

After assembly and final testing, Simon Hegele workers collect the finished system from the assembly lines and take it to the packaging area, where it is protected with special plastic to prevent it from rusting in its trip to the customer, as many of these systems are shipped by sea.

The average lead-time to completely refurbish a system is around **4 weeks**. However, the SPH process does not contribute to the refurbishment lead-time, even though belonging to the Refurbishment step (third step of the 5-step Quality Process). It is so because the spare parts collected on this stage will not integrate ecoline systems but will yes go to a spare parts warehouse to support Customer Service (CS) or to be sold in the aftermarket.

This concludes the description of the third step of the 5-step Quality Process, Refurbishment.

2.2.4. Installation

The installation process corresponds to the penultimate step of the ecoline process (see **Figure 1**). It includes the transportation of the finished ecoline system from Siemens Healthineers facilities in Forchheim to the customer's location, its installation by professionals and its performance-check.

When the ecoline system reaches the customer, it must then be installed by professionals, ensuring it is reliable and ready to fulfil its purpose under a new lifecycle – this is usually done by Siemens' logistic partners trained by Siemens Healthineers, similar to what happens with the de-installation process.

The installation process under expert supervision includes (Siemens AG, 2013):

- Transportation and installation by qualified service providers (in most cases, it refers to Simon Hegele workers trained by Siemens Healthineers);
- Start-up and repeated check-up of the ecoline system's performance;
- Optional application training;
- New user documentation and Proven Excellence certificate.

The complete lead-time guaranteed by Siemens Healthineers for an ecoline order, so from the placement of the order to its delivery at the customer and installation, is **8 weeks**. Priority systems can be delivered in 6 weeks. For FY2019, a total of 105 AT ecoline systems were sold.

2.2.5. Services

Services corresponds to the last step of the 5-step Quality Process. It includes the warranty of the refurbished system, the replacement of broken parts by original spare parts, training for new system users, financial solutions and service contracts.

Ecoline systems are guaranteed a 1-year warranty after purchase and installation of the system – 24 hours a day, 365 days a year, regardless of the location. Moreover, Siemens Healthineers also commits to have available spare parts for the ecoline system for a minimum of 5 years, ensuring that any part in need of replacement will be replaced by an original Siemens spare part. Other services include flexible financing solutions and service contracts and worldwide Siemens Healthineers contact partners.

Also, all ecoline systems "have an unbroken pedigree", meaning that every system is uploaded and updated in Siemens' database, ensuring traceable reliability even after leaving Siemens' facilities (Siemens Healthineers, n.d.).

The overview of the 5-Step Quality Process is illustrated in **Figure 18**.

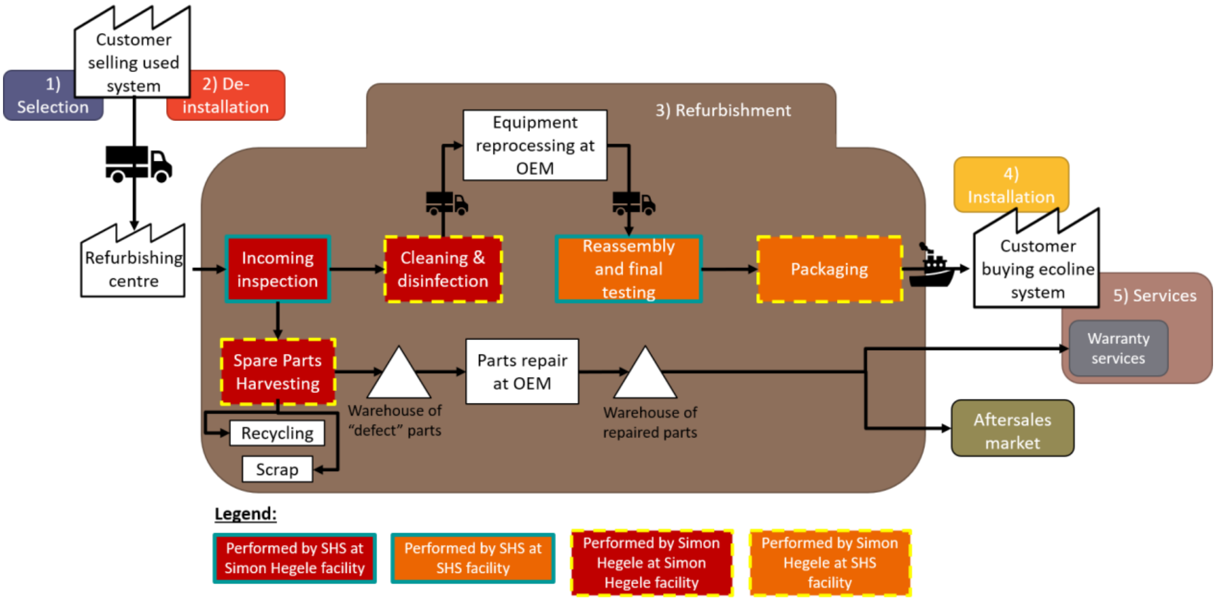

Figure 18. Overview of the 5-step Quality Process

2.3. Challenges encountered in the Spare Parts Harvesting process

The present section aims to present and summarize the challenges encountered in the Spare Parts Harvesting process, which were enumerated and highlighted in yellow in the Spare Parts Harvesting section. These, which are listed below in **Table 10**, were identified and subject of improvement during the 6-month stay at the company between February and July 2020, together with the AT ecoline team, IBD and CS.

Table 10. Identified challenges in the Spare Parts Harvesting process

	Identified challenges in the SPH process
(1)	Outdated spare parts list: eliminate parts that are not currently being harvested nor needed for stock and introduce those which are needed.
(2)	Requirements list is not suitable for the Spare Parts Harvesting (SPH) process, as terminology such as "not relevant" can cause confusion to the worker.
(3)	SPH workers must fill in all serial and revision numbers in the spare parts list, even on those parts clearly identified that are to scrap, substantially increasing the operation time.
(4)	Decision of which RS HP parts are for stock is done based on intuition, when the master data pool file specifies min-max references for spare parts inventory.
(5)	Two e-mails are exchanged between Simon Hegele - Siemens Healthineers to confirm which RS HP parts already disassembled are actually for stock, creating space and time wastes through a non-value-added activity.
(6)	Currently, spare parts needed for stock might be sent to scrap because the spare parts list (1) is not updated.
(7)	Poor space utilization and disorganization of the workshop creates waiting times, motion and space wastes.
(8)	Overall lack of standardization in the process (both in the procedure and in the layout).

The upcoming chapter 4. will explore how the identified challenges were tackled in order to improve the SPH process resorting to a lean philosophy, since its suitability to a remanufacturing context has been proven, as it will be demonstrated in the following chapter 3..

2.4. Chapter conclusions

The second chapter started with a characterization of the company in study, Siemens, then focusing on the strategic company Siemens Healthineers, where the refurbishment of end-of-life medical systems takes place. Inside Siemens Healthineers there are four business areas: Diagnostic Imaging (DI), Ultrasound (US), Advanced Therapies (AT) and Laboratory Diagnostics (LD). This contextualization was necessary to understand where exactly the present work takes place: at the AT business area.

Then, the 5-step Quality Process, which describes the necessary 5-steps to refurbish a medical imaging system according to industry standards, was described in detail. This was possible by observing the process and through several meetings and inputs received during the 6-month stay at Siemens Healthineers Forchheim between February and July 2020. The present dissertation focuses on the Spare Parts Harvesting process, which currently is a time-consuming process due to several inefficiencies already identified in that section. A total of 8 problems were perceived. The following chapter 3. aims at exploring important concepts for the purpose of this dissertation, and mainly to identify strategies to overcome these problems.

3. Literature Review

The present chapter aims to contextualize important concepts that will help understand the terms used throughout the dissertation, as well as introduce the main methodologies and results obtained in previous literature. First, in section 3.1., the theoretical grounds of a circular economy and closed-loop supply chains are established within the scope of the present case-study. Then, in section 3.1.1., the several solutions for managing end-of-life products are presented, introducing the concept of product recovery management and where refurbishment is incorporated. The relevance of the spare parts business was also investigated in section 3.2., so as to understand the impact of the Spare Parts Harvesting process in the company and the main challenges faced with it. Finally, the main challenges that remanufacturing companies face are explored in section 3.3.1.1., and opportunities to become leaner presented in section 3.3.1.2., in order to improve remanufacturing processes. Lean methodologies, tools and practices are also studied in section 3.3.2. and 3.3.3. to find those that best suit the present case-study.

3.1. Cradle to cradle – closing the loop on material flows

The term circular economy (CE) is not new. This concept has drawn attention to the environmental impacts of operations, which became significant with the industrial revolution. Allied to a capitalist system, the individual's mindset shifted from maintaining possessions to discarding products after use (linear consumption behaviour). As consumption increased, the natural world was breaching its limits due to severe pollution, overexploitation of resources and generation of waste (Lieder & Rashid (2016), Mathews (2011)). It was time for governments to act, and new regulations held manufacturers responsible for the whole lifecycle of their products. This introduced recovery networks in the supply chain, where used products were returning to the original equipment manufacturer (OEM) as part of take-back obligations, so they could manage their end-of-life options (Fleischmann, Krikke, Dekker, & Flapper, 2000). Recovery networks establish a link between two different markets: a disposer market where products are discarded after use, and a reuse market characterized by the demand for recovered products, such as Siemens Healthineers' ecoline systems (Fleischmann, Beullens, Bloemhof-Ruwaard, & Van Wassenhove, 2001).

If before the supply chain was traditionally characterized by a forward flow of materials, this would change the paradigm and popularize the concepts of reverse and closed-loop supply chains, aiming at closing material flows by managing their recovery options. Thierry, Salomon, Van Nunen, & Van Wassenhove (1995) distinguished between 8 and aggregated them in 3 categories, as illustrated in **Figure 19**: direct reuse/resale, product recovery management (repair, refurbishing, remanufacturing, cannibalization, recycling) and waste management (incineration and landfilling). As stated by the authors, the objective of product recovery management is to minimize waste by recovering as much as reasonably possible the economic and ecological value of used products. Kumar & Putnam (2008) described the focus on recovery of resources, recycling and reuse as "cradle-to-cradle" resource management.

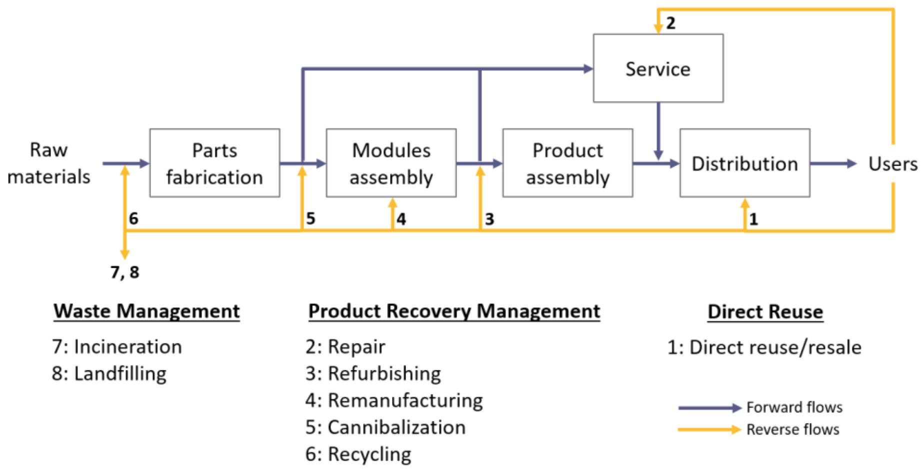

Figure 19. Integrated supply chain

Source: Thierry, Salomon, Van Nunen, & Van Wassenhove (1995).

So, it is in the context of product recovery management that **refurbishing** arises. After reviewing several papers, a certain ambiguity regarding the terms repair, refurbishing and remanufacturing was perceived. For Thierry, Salomon, Van Nunen, & Van Wassenhove (1995), the options differ essentially in the degree of upgrading, where repair involves the least and remanufacturing the largest upgrade. While the purpose of a repair is to restore a product to working order, in refurbishing the result is an upgraded version of the original product, and in remanufacturing a new product is manufactured using components from old systems. For Haynsworth & Lyons (1987), the same point of view is shared: remanufacturing refers to the process of completely disassemble the discarded product, clean usable parts, refurbish them and keep them in inventory (description that corresponds to the Spare Parts Harvesting process of Siemens Healthineers), and reassemble a new product from both old and new parts (recalling Siemens Healthineers AT systems, the proportion is 20/80 old/new). Gharfalkar, Ali, & Hillier (2016) go even further by reviewing the literature that addresses the terms repair, recondition, refurbish and remanufacture, and highlight the lack of clarity and/or overlap between different options. Once again, the conclusion is that in hierarchical terms, remanufacturing is superior to refurbishing. Considering the given perspectives, the refurbishing process of Siemens Healthineers actually finds itself closer to the definition of remanufacturing, proving the ambiguity mentioned before. However, as the refurbishing process of Siemens Healthineers medical systems is in accordance with the NEMA/MITA standard for refurbishment, this is the terminology that will be followed for the context of this dissertation.

Moreover, the Spare Parts Harvesting process addressed in this dissertation is a cannibalization process, according to Thierry, Salomon, Van Nunen, & Van Wassenhove (1995). This because the definition provided refers to sets of reusable parts from used products that are purposely recovered for repairing, refurbishing or remanufacturing other products. An example of a U.S. company with focus on cannibalizing integrated circuits out of computers is provided: when receiving the computers, these are disassembled in order to recover only those specific parts that can later be sold. In analogy, Siemens Healthineers' medical systems enter the Spare Parts Harvesting process so specific parts, determined by Customer Service, can be removed and stored in a spare parts warehouse to assist in the repair of medical systems at the customer or to be sold in the aftermarket.

3.1.1. Motives for product recovery

Many have been the authors that place the causes for product recovery in legal, economic and social drivers (for example, Thierry, Salomon, Van Nunen, & Van Wassenhove (1995), Ravi, Shankar, & Tiwari (2005), Lundmark, Sundin, & Björkman (2009)). However, one interesting study by Seitz (2007) presented new findings in terms of motives for remanufacturing that contradict what is usually found in the literature. The author has conducted a 3-year research across 5 automotive OEM remanufacturing companies to understand the **real** motives that lead them to remanufacture engines, the product group under research and which was purposely chosen because it was one of the first automotive products to be remanufactured. Since many of the study's motives match Siemens Healthineers' motives for refurbishing, this subject is of interest to explore. The author distinguished between motives that have a low degree of influence in inducing OEM engine remanufacturing, the "classic motives" often referred in the literature, from those with a high degree of influence and that are registered as "new observations".

The classic motives, according to the author based on academic literature, are due to a moral and ethical responsibility, environmental legislation and profitability. Regarding the **ethical and moral responsibility**, the results from the case-studies revealed that key-words such as "ethics", "green consumerism", "green marketplace", "pressure from society" or "environmental responsibility" were never mentioned by the interviewees as motives for engaging in remanufacturing, and therefore could not be assumed as a "real world motivator". On the **product take-back and recovery legislation**, findings show that automotive remanufacturing companies have been operating long before there was a sense of responsibility towards the environment and recovery legislations were established (such as the End-of-Life Vehicle Directive), since it goes back to the scarcity of materials during the Depression, the Second World War and the demands from the racing industry. As for the **profitability of remanufacturing**, all OEM remanufacturers in the research agree that their operations are not profitability driven and are less likely to be profitable when compared to independent remanufacturers due to the fact that, to prevent independents from gaining access to their products, they will buy any core (used products recovered for remanufacturing) back regardless of the price to pay, and due to the fierce competition for used engines, core prices naturally increase. They see remanufacturing more as a necessity to provide quick answers to their customers' necessities (such as replacements) and to exclude competition, rather than an opportunity to profit more (Seitz, 2007). This reason was also perceived in the Siemens-Healthineers case-study, as Siemens buys back any used system to prevent competitors to lay hands on them.

The "new observations" are motives discovered by the author, different from those in the literature, and that seemed predominant over all "classic motives". The first identified motive has to do with aftermarket reasons: to **secure spare parts supply and warranty**. When car models are discontinued and are no longer in serial production, cores might turn to be the only option to secure spare parts. In addition, vehicle manufacturers become dependent on suppliers in terms of parts price, which increases sharply due to demand and scarcity in the market. Therefore, incorporating remanufacturing activities means that the OEM are able to recover discontinued parts, as well reducing their dependency on suppliers (Seitz, 2007). This was also the case for Siemens Healthineers and pointed out in section 2.2.3. as one of the reasons for Spare Parts Harvesting. The next decisive motive is **market share and brand protection**. Similarly to the reasons pointed out by Siemens Healthineers to incorporate a refurbishing process, the study also found that vehicle manufacturers "*don't want other remanufacturers to "play around" with its engines*", in order to protect the brand name and technology, as well ensuring the top-quality expected by customers (Seitz, 2007). Finally, **customer orientation** was the last identified "real" motive for engine remanufacturing by the OEM and there are at least 3 motivators identified in the research: 1) companies engaged in remanufacturing are able to provide their customers with original spare parts for long periods of time, reasonably fast and at an appealing price; 2) remanufacturing reinforces customer service by promoting a service and repair network "just in case", adding the fact that customers feel safer in having their cars inspected by the OEM; and 3) remanufacturing enables companies to present a wider portfolio of products which includes remanufactured products (as is the case of Siemens Healthineers, with the ecoline portfolio) (Seitz, 2007).

As Siemens Healthineers is the OEM of its medical systems and as analogous reasons for refurbishment were identified with the ones in the study by Seitz (2007), these findings were worth mentioning. **Table 11** provides a summary table identifying those findings which also apply to Siemens Healthineers in regard to the refurbishing of medical systems. However, this characterization lacks future validation work.

Table 11. Siemens Healthineers reasons for refurbishing, based on the work of Seitz (2007)

	Reasons for remanufacturing, applied to Siemens Healthineers	**Degree of influence to induce OEM remanufacturing**	**Seitz (2007) findings applied to Siemens Healthineers**
New observations	Secure spare parts supply	High	• Decreasing dependency on suppliers with regard to prices and spare parts availability • Remanufacturing is one way to source spare parts no longer in production • Remanufacturing is technically and economically more viable than a reproduction • Balancing aftermarket demand through remanufacturing
	Market share and brand protection	High	• Controlling quality of remanufactured systems • Building "quality image" for own products by promoting employee skills and sophisticated equipment • Thorough core collection as universal key to excluding independents
	Customer orientation	High	• Availability of extensive, reasonably priced aftermarket range, "just in case" • OEM takes care of used units, increasing feeling of safety in the customer • Stock replenishment time reduction

Source: Seitz (2007).

As seen, one of the main reasons for product recovery and remanufacturing is to secure spare parts supply and warranty and to improve customer service. In fact, it is in this context that the Spare Parts Harvesting process of Siemens Healthineers arises. It is therefore relevant to explore the impact of a spare parts business on a company and what are the associated challenges so scientific support can be found to adequate answers to the case-study addressed in this dissertation. The following section focuses on this subject.

3.2. Impact of spare parts businesses and associated challenges

3.2.1. Spare parts business

In section 1.1. “a glimpse” of the economic potential of the spare parts business was provided. Now, this subject will be further developed in order to contextualize why it is relevant for Siemens Healthineers Forchheim to improve the Spare Parts Harvesting process, as well the challenges that have been associated with the spare parts inventory management and logistics.

The sales of spare parts and after sales services have become a bountiful source of income to companies. In fact, in the U.S.A. consumers spend around $1 trillion every year on assets they already own (Cohen, Agrawal, & Agrawal, 2006). However, some companies still underestimate the potential of aftermarket businesses (Cohen, Agrawal, & Agrawal (2006), Gallagher, Mitchke, & Rogers (2005)).

Wagner & Lindemann (2008) developed a case-study whose aim was to better understand which problems engineering companies face with their spare parts supply chain and consequent managerial decisions, so as to identify strategic aspects that help build solid revenue and profit from the spare parts business. For that, they’ve chosen 7 “spare parts intensive engineering companies” whose primary product are machines. This research is of particular interest to this dissertation given the similarity of the analysed companies with Siemens Healthineers, namely regarding their geographic and technological context, and market position. These are technology-based companies headquartered in German-speaking countries (3 in Switzerland, 3 in Germany and 1 in Austria) but with operations worldwide. They operate in competitive environments with a high rate of technological change. Moreover, most of them are world market leaders for their products, just like Siemens Healthineers. The results from their research highlight key areas that companies should focus on if trying to make the most out of the spare parts business, and include: improving inventory planning, utilizing the capabilities of LSPs (logistics service providers), enhancing knowledge of installed base, formulating and communicating spare parts strategies, and increasing top management awareness. Although these 7 companies still have room to grow in matter of spare parts SCM, their revenues are already substantial and pertinent to the present case-study, as they evidence the economic relevance of a spare parts business in an engineering industry context, with revenues of spare parts sales accounting to an average of 13.3% of their total revenues (minimum 3.2% and maximum 35%), translating the financial opportunity of such a business.

Other economic evidences were found in 10 other German machine and plant manufacturers analysed by Wagner, Jönke, & Eisingerich (2012). Once again, this study is of relevance for this dissertation because these are engineering German companies, like Siemens Healthineers, and whose spare parts logistics range from “highly professional” to “underdeveloped”. It can be taken from their research that, for top performers, the spare parts revenues accounts, in average, for 20.5% of the total revenues (minimum 10% and maximum 25%), as for bottom performers accounts only, in average, 3.6% (minimum 3.6% and maximum 30%). This can prove to be a good motivator for companies to further invest and develop their spare parts business, as companies who have done so and present a well-aligned spare parts logistics strategy, as well take into consideration the 9 aforementioned components, present higher spare parts revenues with a significant percentage over the total revenues.

3.2.2. Challenges with spare parts inventory management and logistics

The research by Wagner, Jönke, & Eisingerich (2012) identified 9 critical components, through the literature review and the case-study research, that are key to build a "superior spare parts logistic strategy", and grouped them into 3 to create a "Three Step Model" to tackle spare parts logistics, illustrated in **Figure 20**. This figure serves as a basis for exploring the main challenges that companies face in dealing with the spare parts inventory management and logistics.

STEP 1: IDENTIFY THE CONDITIONS				
Spare parts market	**Product characteristics**		**Maintenance strategy of the customer**	**Spare parts obligations**
• Economic situation • Profitability of the spare parts business • Market entry barriers • Number of market players • Competition intensity • Turnover rate of spares	Primary product • Installed base • Product lifetime • Operation intensity • Construction-conditioned product structure • Relevance of a product for all of the customers' business activities	Spare part • New part or remanufactured part • Reparable part or expendable part • Wear behaviour of spares	• Failure-based maintenance • Condition-based maintenance • Time-based maintenance • Selective maintenance	• Delivery commitments (legal/voluntary obligation) • Service/maintenance contracts • Spare parts portfolio/assortment

STEP 2: ANTICIPATE FUTURE DEVELOPMENTS	
Primary product life cycle	**Forecasting methods**
• R&D • Production • Utilization	• Subjective estimations • Indicators and coefficients • Stochastic methods • Model-based methods

STEP 3: ALIGN THE KEY COMPONENTS OF A BUSINESS' SPARE PARTS LOGISTICS STRATEGY TO IDENTIFIED CONDITIONS AND ANTICIPATED FUTURE DEVELOPMENTS			
Goals of the spare parts business	**Supply options**		**Inventory options**
• Revenue/profit • Customer loyalty • Differentiation • Image • Diversification	Supply in the production phase • Spares out of regular series production • Spares purchasing • Reconditioning of used parts	Supply in the utilization phase • Internal production or external production • Separate workshop • Utilization of compatible parts • Final stock • Reconditioning of used parts • Reutilization of used parts	• Degree of warehouse centralization • Vertical/horizontal storage structure • Location choice • Inventory levels • Costs (storage costs/inventory infrastructure costs/transport costs) • Reactivity/efficiency of spares provision

Figure 20. Three-Step Model: Key Components of a Spare Parts Logistics Strategy

Source: Wagner, Jönke, & Eisingerich (2012).

Step one, identifying the conditions, concerns with conducting a market analysis of spare parts business (1), assessing the product characteristics (2) and the maintenance strategy of the customer (3), and determining the spare parts obligations (4) (Wagner, Jönke, & Eisingerich, 2012). In this regard, it can be concluded that Siemens Healthineers has the conditions very well defined, or it wouldn't be one of the world leaders in the healthcare industry. It becomes relevant to analyse in greater detail step 2 and 3.

The second step is to anticipate future developments considering the product life cycle (5) and forecasting methods (6). Both components are deployed at Siemens Healthineers. The authors consider three product life cycle phases: R&D (where technical characteristics are specified, impacting the requirements for spares and influencing aftersales service), production (where the primary product is manufactured and the provision of spares begins, also selecting the best supply strategy for the next phase) and utilization (where the service cycle terminates, that is, the pre-established point to end the supply of spares) (Wagner, Jönke, & Eisingerich, 2012). As for forecasting methods, there is extensive literature on forecasting spare parts demand, but a study by Dekker, Pinçe, Zuidwijk, & Jalil (2013) is of interest to mention because their approach has similarities with the approach perceived at Siemens Healthineers (however, this was not confirmed). They use a forecasting model using the installed base information. Recalling the definition of installed base in section 2.2. elaborated by these same authors, is the "*whole set of systems/products for which an organization provides after sales services*". This forecasting model uses therefore both historic demand data and data about the installed base. As Siemens Healthineers has its own Installed Base Development (IBD) department, which is in strict cooperation with Customer Service (CS), responsible for forecasting spare parts demand, and each product line, it is believed that the installed base forecasting model is adopted. Yet, it is not in the scope of this dissertation to explore or improve possible forecasting scenarios, so this subject will not be deepened. What is interesting to highlight in their paper are the 4 main issues in spare parts logistics that aggravate the collection of good quality data to feed the forecasting model, and which were also perceived at Siemens Healthineers: lead-times, demand characteristics, information sharing, and product life cycle.

LEAD-TIMES. There are essentially two relevant lead-times in the spare parts logistics: the transport lead-time, which refers to the delivery time of a part from a depot/stock location to a customer, and the manufacturing lead-time, which refers to the time needed to source and produce a part according to requirements, and bring it to the service network, i.e., to stock locations keeping inventory of spare parts (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). In the case of Siemens Healthineers, the manufacturing lead-time can either refer to 1) the sourcing and placing of an order for a new part to suppliers or 2) to the sourcing (harvesting) and booking of a "defect" part from the 2081 warehouse (the warehouse for harvested parts from used-systems), which is then reconditioned at the OEM in order to become a "new" part. In the first case, the lead-time is entirely up to the supplier, which has to manufacture the ordered part according to the specifications and deliver it to Siemens Healthineers; in the latter case, the lead-time is the sum of the time it takes for Siemens to harvest the needed part (in the Spare Parts Harvesting process) plus the time it takes for the OEM to recondition it. However, it can also happen that the needed part is readily available in the 2050 warehouse (the warehouse for spares that were already reconditioned at the OEM), and therefore this situation is in the scope of transport lead-time, and not manufacturing lead-time. The choice of stocking locations of spare parts also impacts the lead-time. One can choose to keep a central stock location responsible for supplying a large number of customers, or several regional depots located nearer the customer (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). For the case of Siemens Healthineers, as previously seen in section 2.2.3., there are only 3 central spare parts warehouses satisfying the orders of all customers located on that part of the globe. Therefore, according to the authors, Siemens Healthineers must determine the optimal stock of spare parts to satisfy demand where tools such as demand forecasting and inventory management become essential. Else, to support decisions that concern with lead-time, like deciding the optimal warehouse and refurbishing centre locations, the concept of supply chain design is of interest to explore in future work.

DEMAND CHARACTERISTICS. As Dekker, Pinçe, Zuidwijk, & Jalil (2013) put it, "*the demand for spare parts is usually intermittent, erratic and slow moving*". That said, the main characteristic of spare parts demand is the substantial degree of uncertainty aggregated to it, and supported by the research of Eaves & Kingsman (2004), the authors conclude that forecasting based on time series analysis is not viable as little data is available.

Moreover, one might think that safety stocks are a solution to buffer uncertainty, however, as parts are usually expensive, have a high rate of obsolescence due to short product life cycles, and given the fact that most spare parts inventories are made up of a wide variety of different parts, increasing the necessary investment, spare parts inventory also has an associated risk.

INFORMATION SHARING. Pooling inventory between different service providers is seen as an opportunity to optimize spare parts inventory. However, due to competition between OEM and service providers, and to the perceived value of information like installed base, inventories and demand, this is usually not the case among supply chain collaborators (the authors refer to Veenstra, Zuidwijk, & Geerling (2006)) (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). In fact, this was verified in Siemens Healthineers – there's no information sharing among any SC partners, due to competitivity issues, and there's also no inventory pooling among the 3 central warehouses, in part due to competitivity but also due to the lack of a centralized information system, making it difficult to assess information regarding spare parts availability among warehouses. In the context of industrial engineering, implementing a centralized information system would also be an opportunity to explore in future work.

PRODUCT LIFE CYCLE. Elaborating on what was said earlier, the demand for spare parts is inherent to the product life cycle AND to the size of installed base, which allowed the authors to develop a forecast method based on previous works (e.g. Solomon, Sandborn, & Pecht (2000), Inderfurth & Mukherjee (2008)), illustrated in **Figure 21**. Similarly to the work of Wagner, Jönke, & Eisingerich (2012), three phases of the product life cycle are considered: the initial or ramp-up phase, the mature or maintenance phase, and the end-of-life phase. Demand for spare parts in an initial phase might be explained due to quality problems. Nevertheless, consumption of spares usually grows during the maintenance phase due to deterioration and random failure of the product. In the end-of-life phase, after the production of the part has ceased, it usually occurs what is called "last time buy" (Dekker, Pinçe, Zuidwijk, & Jalil, 2013) – in Siemens Healthineers, this is done by Customer Service and refers to an estimation of spare parts demand over the remaining service period of the system, so they can place a last/final order for that part to suppliers. This forecast is essential to determine the size of the final production run and to ensure enough inventory to support active systems. To meet the "last time buy" demand, it might also be needed to account for the availability of returned parts (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). In Siemens Healthineers, this is what triggers the Spare Parts Harvesting process. Moreover, the value of spare parts also has an impact on the product life cycle – it can be expected that expensive parts have a shorter life cycle compared to low value parts, because their high maintenance costs will promote new purchases. Additionally, forecasting deterioration and failure is also relevant because these are some of the reasons that trigger spare parts demand. Therefore, information about the technical condition of the products should also be used to forecast demand because it impacts it (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). There is available literature on this topic (the authors refer to Wang (2002)), and together with the previous research opportunities, this would also add substance to future work in matter of improving spare parts inventory management.

Hereupon, the conditions are now gathered to move to step 3 (recall **Figure 20**), which has to do with adjusting the strategy with the market conditions previously identified in order to anticipate future developments from the second step, by defining the goals of the spare parts business (7), and the supply (8) and inventory options

(9). Concerning the goal of the spare parts business, Siemens Healthineers aims at covering all options (revenue/profit, customer loyalty, differentiation, image, diversification).

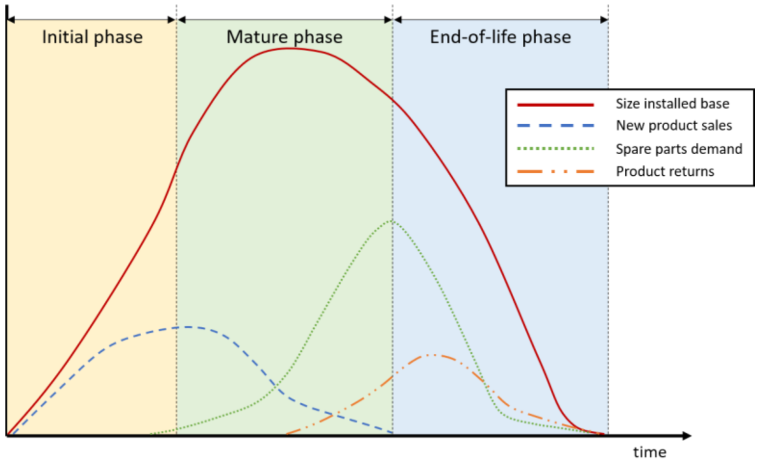

Figure 21. Product life cycle with installed base size, demand for product, demand for spare parts and product returns

Source: Dekker, Pinçe, Zuidwijk, & Jalil (2013).

As for the supply options, Wagner, Jönke, & Eisingerich (2012) distinguish between supply in the production phase and in the utilization phase (this situation is illustrated in **Figure 22**). During the production phase, where the provision period of spares begins, the supply is rather uncomplicated: spares required at this phase are usually due to early failures so they can either be picked out of the regular series production, purchased from the suppliers or by reconditioning used parts. During the utilization phase, supply options must usually cover long provision periods which becomes particularly challenging because spares can no longer be picked out of the regular series production. In their case-study, most companies pursue internal (own production) or external (outsourcing) spares production. Reconditioning used parts is also a popular choice. For the purpose of this dissertation, it only makes sense to focus on the production phase of ecoline systems (Siemens Healthineers refurbished systems). It is important to re-mention that ecoline systems are made of 80% new parts and 20% used parts. That said, the three supply options indicated in **Figure 22** are used: the parts manufactured by Siemens can be taken out of the regular production series, the ones that are not must be purchased from the OEM and parts that can no longer be found at the OEM must be recovered through the Spare Parts Harvesting process and reconditioned. This is also true for the production of new systems, except that no used parts are incorporated in this part of the process. As for the supply options in the utilization phase (whether it is a new or refurbished system) the supply options covered by Siemens are: final stock (the stock resulting from the "last time buy" mentioned earlier), internal production if available, external production if available and reconditioning of used parts if the previous two are unavailable.

According to the authors, companies with a "highly professional" spare parts logistics in the sample, designated as "top performers", consider all 9 components, although with different priorities. As it was seen, Siemens Healthineers would therefore be characterized as having a "highly professional" spare parts logistics.

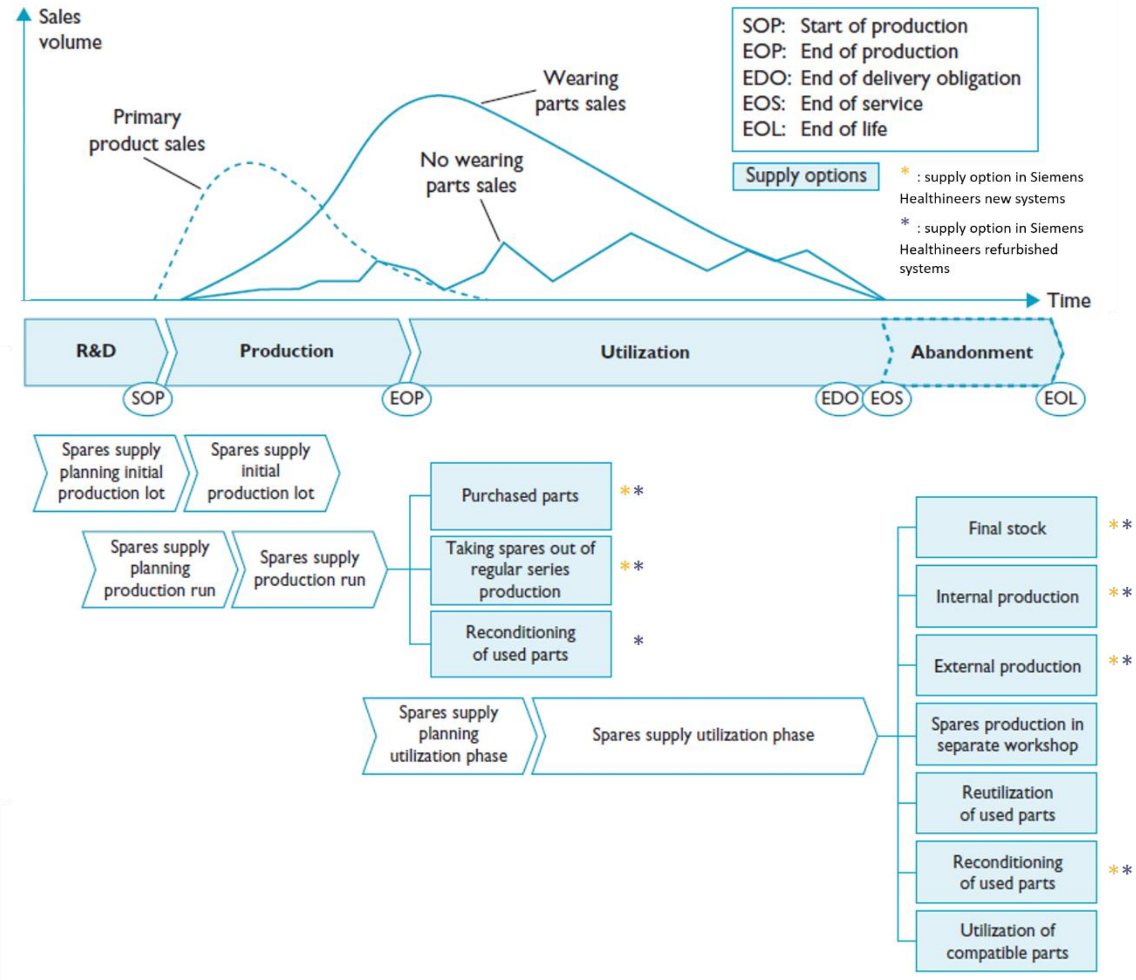

Figure 22. Spare parts supply options along the product life cycle, with highlight to options covered by Siemens Healthineers

Source: Adapted from Wagner, Jönke, & Eisingerich (2012) to highlight options adopted by Siemens Healthineers.

Managing the inventory of spare parts is particularly challenging due to their volatile and erratic demand, as many authors have pointed out (Wagner & Lindemann (2008), Chen, Lam, Ramakrishnan, & Auston (2010), Jalil, Zuidwijk, Fleischmann, & Van Nunen (2011), Wagner, Jönke, & Eisingerich (2012)). Moreover, companies often include warranty programs in which they must secure spare parts provision for years, as is the case for the company addressed in this case-study. From the research by Wagner, Jönke, & Eisingerich (2012), the average length of the spare parts provision period from the 10 engineering companies was 22.75 years. This translates in high holding costs and might eventually turn into high obsolescence costs. Therefore, optimizing inventory management policies in order to prevent both stockouts, which leads to unsatisfied customers, and overstocks, which leads to obsolete inventories, seems to be a common goal (Eaves & Kingsman (2004), Porras & Dekker (2008), Louit, Pascual, Banjevic, & Jardine (2011), Dekker, Pinçe, Zuidwijk, & Jalil (2013)).

To conclude, the delivery of service (short lead-times) and long-time availability of spares are highlighted as two of the most valued features for spare parts customers, who have high expectations in this regard (Wagner, Jönke, & Eisingerich, 2012). The time taken to harvest spare parts from end-of-life systems has impact on the delivery of service lead-time to customers, because the longer the Spare Parts Harvesting process, the longer it takes for the parts to go to the OEM to be reconditioned and the longer it takes to be ready to send to the customer. For this reason, the goal to improve Siemens Healthineers Spare Parts Harvesting process was established. As lean has been extensively used in the industry to optimize processes, and with great impact on lead-time reduction (by implementing lean practices, Kurilova-Palisaitiene & Sundin (2014) discovered that the lead-time of a forklift truck remanufacturer could be reduced by 93%), this methodology will be explored in the following section to investigate its suitability for the present case-study.

3.3. Lean in remanufacturing industries

Lean has its roots in Japan with the Toyota Production System (TPS). In their iconic book, Womack, Jones, & Roos (1990) spent 5 years researching the differences of mass and lean production in one of the world's leading industries, the automotive, and conclude that "*the principles of lean production can be applied equally in every industry across the globe*". Supporting this statement was the sharp increase of lean popularity worldwide, with a variety of industries evidencing the dramatic results of lean implementation. However, some authors debate the universality of lean production, especially in remanufacturing industries, due to the high uncertainty this industry is subject to regarding the quantity, quality and timing of the returned used products, which consequently impacts the whole remanufacturing system in terms of process lead-time, inventory management and production planning (Priyono & Idris, 2018). In addition, the remanufacturing process incorporates activities which are exclusive to this industry, such as disassembly, cleaning, inspection and sorting, adding complexity to this system (Geyer & Jackson (2004), Lundmark, Sundin, & Björkman (2009), Pawlik, Ijomah, & Corney (2013), Kurilova-Palisaitiene & Sundin (2014)).

In section 3.3.1., the challenges and opportunities of lean implementation in remanufacturing industries are explored. In the following section 3.3.2. and 3.3.3., lean tools, methodologies and practices used to identify challenges in the process and to improve them are reviewed, respectively.

3.3.1. Challenges and opportunities in lean remanufacturing

3.3.1.1. Challenges

Remanufacturing industries have specific characteristics that distinguish them from the conventional production system, and which represent a greater challenge to the implementation of lean. The main difference is that remanufacturers have to deal with reverse logistic flows to recover used products, and incorporate remanufacturing operations such as inspection, disassembly, cleaning, sorting, reassembly, testing, which make the system more complex (Sundin (2006), Östlin & Ekholm (2007), Lundmark, Sundin, & Björkman (2009)). Priyono & Idris (2018) analysed how remanufacturing companies behaved in 14 characteristics compared to the Toyota Production System (TPS), the "lean role model", and differences were noted, for example, regarding time perspective (remanufacturers short-term orientation vs. TPS long-term orientation), process choice (remanufacturers batch production vs. TPS continuous production) and quality management (remanufacturers knowledge acquired through trial and error vs. TPS culture of doing things right the first time), among others.

The authors also point to the fact that remanufacturers are not value creators as lean manufacturers, instead they adopt lean manufacturing as a way to recover as much as possible of the value from used products.

The main challenge perceived across all reviewed papers lies in the high uncertainty this industry is subject to, namely with regard to the timing (when), quality (in which condition) and quantity (how many) of incoming cores, and which impact the entire production planning and scheduling, making it more difficult to accomplish (Sundin (2006), Östlin & Ekholm (2007), Lundmark, Sundin, & Björkman (2009), Kurilova-Palisaitiene & Sundin (2014), Priyono & Idris (2018), Kurilova-Palisaitiene, Sundin, & Poksinska (2018)). Guide Jr. (2000) specified seven challenges, where most researchers until then only mentioned four: 1) uncertain timing and quantity of returns, 2) the need to balance returns with demands, 3) the disassembly of returned products, 4) the uncertainty in materials recovered from returned items, 5) the requirement for a reverse logistics network, 6) the complication of material matching restrictions, and 7) the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times. The number of perceived challenges increased over time to include, for example, managerial challenges (miscommunication, lack of employee commitment or skills, poor cross functional collaboration, etc.). Having these challenges identified, Kurilova-Palisaitiene & Sundin (2014) categorized them into 3 major remanufacturing challenges: product quality, process lead-time and inventory level. In the process lead-time, the authors mention the time waiting for spare parts delivery as a non-value-added activity with impact on it. Although this waiting time refers to when a spare part is missing in the remanufacturing process (that is, in the reassembly process of the remanufactured product), it can be concluded that the time needed for harvesting spare parts most surely impacts the remanufacturing process, in case of low spare parts inventory. For that reason, it makes sense to optimize the productivity of the Spare Parts Harvesting process by reducing the lead-time to harvest one system, as process lead-time is one of the main constraints in the remanufacturing process.

In a different study, Kurilova-Palisaitiene, Sundin, & Poksinska (2018) also reveal that the time waiting for or collecting spare parts is one of the reasons for long and variable remanufacturing lead-times. In fact, on the average of the four companies in the case-study under analysis, it contributed to an increase in process lead-time in 20.25 days. There are several reasons behind this: poor cooperation and communication among product life cycle stakeholders, inexistence of a material requirements planning system (MRP) to control the material flow and long delivery times of special spare parts. An ineffective communication between Siemens Healthineers (the OEM) and Simon Hegele (the contracted company to perform some refurbishing operations, such as Spare Parts Harvesting) was in fact one of the main appointed causes for the Spare Parts Harvesting process unproductivity.

In sum, the main challenge within remanufacturing industries is to tackle the high uncertainty of cores supply, mainly in terms of quantity, quality and timing. This factor impacts the whole remanufacturing process, which is characterized by lead-time fluctuations and process variability, and therefore makes implementation of lean production principles difficult. It was discovered that waiting for spare parts is also a major challenge in remanufacturing industries, supporting Siemens Healthineers' choice to improve the Spare Parts Harvesting process.

3.3.1.2. Opportunities

To find improvement opportunities in seven remanufacturing companies, Sundin (2006) resorted to the Rapid Plant Assessment (RPA) methodology which consists of two assessment tools, the RPA rating sheet and the RPA questionnaire. The RPA rating sheet presents 11 categories for assessing the leanness of a plant, and the questionnaire consists of 20 yes-or-no questions to determine if the plant uses best practices in these categories. In each category, companies are ranked from 1 (poor) to 11 (best in class), therefore categories with low rankings instantly provide a visible opportunity for improvement. These categories are: 1) customer satisfaction, 2) safety, environment, cleanliness & order, 3) visual management system, 4) scheduling system, 5) use of space, movement of materials, and product line flow, 6) levels of inventory and work in progress, 7) teamwork and motivation, 8) condition and maintenance of equipment tools, 9) management of complexity and variability, 10) supply chain integration, and 11) commitment to quality. The results show that, in general, the case-study companies scored lower on categories 3, 5 and 6, therefore these represent good opportunities to achieve a leaner remanufacturing system. On the contrary, the higher scores were on categories 1, 7, 9 and 11, translating the categories where remanufacturing companies perform better from a lean perspective. In fact, these results are in line with what was observed in the Spare Parts Harvesting process.

By quantifying the lean gap between manufacturers and remanufacturers, Kurilova-Palisaitiene & Sundin (2014) were able to highlight “critical to success business” categories where companies have the potential to improve. Manufacturers and remanufacturers were scored from 1 to 4 in 19 categories collected through literature review (1 corresponding to the least lean scenario and 4 the most), allowing to assess the leanness of both systems in different business indicators: revenue forecast, operating costs, competition, material flow, lead-time, volume, automation, batch size, planning horizon, product variation, DFRem (design for remanufacturing), inventory level, yield, quantity, quality, timing, communication, collaboration, sharing risk. Manufacturers scored higher in 17 of the 19 categories, with an average score of 2.92, meaning that they have still not fully accomplished lean manufacturing; remanufacturers have lower operating costs than manufacturers (supported by literature review) therefore scored higher in this regard, and both scored equally low in the design for remanufacturing category, because as manufacturers increase product variability, remanufacturers face more challenges, bringing design issues from each side closer together. The average score for remanufacturers was 1.37, meaning they have great potential for improvement in terms of lean in all categories that scored lower. Moreover, the authors present a theoretical pathway towards lean remanufacturing by means of a lean remanufacturing pyramid. The transition to lean is achieved by improving material and information flows, as well overcoming, on a first level, uncertainty and complexity from the outside, then internal challenges such as inflexibility to adapt to customers’ demands and variability caused by process and material fluctuations, and lastly the seven lean wastes.

3.3.2. Lean methodologies, tools and practices to identify challenges in the process

There are several lean methodologies that are employed in order to identify challenges or improvement points in processes. The most utilized tool across reviewed papers was the Value Stream Mapping (VSM). This was the case for Östlin & Ekholm (2007), who analysed if lean production principles could be implemented in a toner cartridge remanufacturer to improve material flows, and for Pawlik, Ijomah, & Corney (2013), who studied the journey of an automotive remanufacturer towards lean.

Value Stream Mapping helps companies understand their current situation by capturing all processes, material and information flows within a given product family, which then makes it easier to identify wastes in the system and outline a future state vision (Liker, 2004). It helps to distinguish between value-added and non-value-added activities, aiming to eliminate the latter (Liker (2004), Melton (2005)). **Process flow mapping**, **time-value mapping** and **spaghetti diagramming** are data collection activities that serve as input/feed the VSM (Melton, 2005). Kurilova-Palisaitiene & Sundin (2014) use the concept of VSM to present a workshop specifically designed to identify challenges and improvement opportunities by following material and information flows – the MiniMiFa workshop (minimum time for material and information flow analysis). The MiniMiFa is performed in three steps: 1) Mapping the process and the actors, 2) Identifying process challenges, and 3) Collecting and prioritising improvement ideas.

Also important is to discover the root-cause of the symptoms revealed by the data analysis (Melton, 2005). The **cause-and-effect diagram**, also known as **Ishikawa diagram**, is one of the possible root-cause analysis tools. Ishikawa (1976) described the implementation of this tool in five steps, illustrated on **Figure 23**: 1) decide on the problem to improve or control, 2) write it at the far-right end of an arrow, 3) consider the main factors that might be affecting the problem, aggregate them into groups (for example, methods, manpower, environment, machinery (Andersen & Fagerhaug, 2006)) and direct a branch arrow to the main arrow, 4) for each branch specify the detailed factors, which may be regarded as causes, 5) check if all factors are identified and cause-effect relationship properly illustrated; if yes, the diagram is complete.

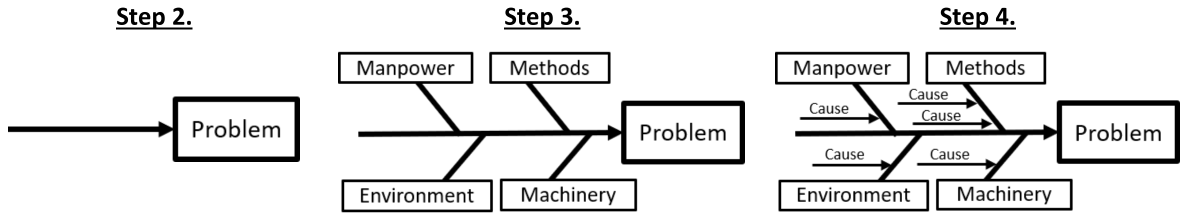

Figure 23. Cause-and-effect diagram construction (steps 2-4)

Source: Ishikawa (1976) and Andersen & Fagerhaug (2006).

It was also seen that in the case-study by Pawlik, Ijomah, & Corney (2013), daily **shopfloor meetings** are useful to identify problems by sharing ideas, concerns and provide feedback between managers and employees. Those problems were investigated and resolved resorting to the Ishikawa diagram, 5-Whys and histograms. The 5-Whys technique consists of asking to the symptom of the problem "why?" several times (but as a rule of thumb, usually no more than 5 times is required) to reveal the core of the root causes (Andersen & Fagerhaug, 2006). A histogram, in turn, is used to display the distribution and variation of a data set, which helps determining the dominant cause (Andersen & Fagerhaug, 2006).

At last, Sundin (2006) presented 6 data collection options suitable to identify specific challenges in the process, and are summarized in **Table 12**: the **RPA method** mentioned earlier in section 3.3.1.2., **process mapping**,

manager interview, **personnel interview**, **observations**, and other methods which are not specified. Several data collection methods can be used within the same case-study, process that is designated as "triangulation" (Sundin (2006), Kurilova-Palisaitiene (2018)).

Table 12. Data collection methods suitable to identify specific challenges in the process

	Obstacles in the process	Bottlenecks in the process	Process layout (remanufacturing steps)	Process organization	Reverse logistics
"Read a plant"	X	X		X	
Process mapping			X		X
Manager interview	X	X	X	X	X
Personnel interview	X	X		X	
Observations	X	X	X		
Other methods	X		X	X	X

Source: Sundin (2006).

3.3.3. Lean methodologies, tools and practices to improve processes

After identifying the possible lean methodologies, tools and practices that can be used to identify challenges in the process, it is now relevant to present those that can be implemented to tackle those challenges.

Östlin & Ekholm (2007) refer 7 lean methods that especially cope with material flows: 1) **pull production system** (Make to Customer Order), 2) **create a levelled workload**, 3) **one-piece flow**, 4) **reduced setup times**, 5) **takt-time**, 6) **just in time deliveries** and 7) **stable production process**. In the authors' case-study, although there were some challenges that hindered the implementation of lean production principles, like those analysed in section 3.3.1.1. (uncertainties in the material recovery rate, variable processing times and lack of systems for just in time delivery), such was possible with some constraints. In fact, their study proved that a workshop layout could be significantly improved resorting to lean production principles. The authors noticed that there were inefficiencies regarding the transportation of components between workstations and the collection of tools needed to perform an operation. These wastes of motion could be avoided by effectively using the available space at the workshop and rearranging workstations in a logical order. The current layout did not allow for a straight flow and the tools and materials needed for operations were not placed nearby workstations, which translated in wastes of motion and unnecessary costs resulting from increased transportation and operational time. The authors then suggested to organize the workshop to a **straight flow** and **place material storages close to the workstations**. Consequence of this would be decreased setup and transportation times, as well lower batch sizes; the production would become easier to control, the lead-time would shorten, and the remanufacturing process would become more flexible. The results from this research encouraged the reorganization of the Spare Parts Harvesting workshop at Siemens Healthineers because there too were perceived wastes of motion related to material flows, which this study confirms is possible to improve or even eliminate using a lean approach.

Kanikuła & Koch (2009) addressed how one can improve disassembly and reassembly processes using the following lean methods: **one-piece flow**, **pull system**, **visual control**, **Kanban system**, **SMED** (Single Minute

Exchange of Die), **TPM** (Total Productive Maintenance), **Kaizen**, **Glenday Sieve**, **Value Stream Mapping**, and **PFEP** (Plan For Every Part). What is interesting from their study is one lean scenario developed to tackle the instability in the percentage of parts recovery at disassembly and when it is recommended to keep inventory of repaired parts, and which portrays the current situation of the refurbishing process at Siemens Healthineers in a leaner way. Cores received at the remanufacturing company have to be immediately disassembled (just like at Simon Hegele Refurbishing Centre). In this scenario, there is a warehouse of disassembled parts and a supermarket of repaired parts. When an order appears in the reassembly process, the required repaired part is taken from the supermarket, reassembled together with new parts and shipped to the customer (following a Kanban system). Those parts picked up from the supermarket have to be replenished by repair process. What differs from this scenario for the Siemens Healthineers refurbishing process is that, first, the repaired parts are not used in the reassembly process, instead they are used for warranty services or to be sold in the aftermarket, and this way a pull and kanban system is also not implemented for replenishment. Then, the supermarket of repaired parts is in fact a warehouse of repaired parts at Siemens Healthineers. Nevertheless, the warehouse is replenished by the repair process, the same way suggested by the authors' scenario. **Figure 24** was adapted to portray Siemens Healthineers' current situation, which could be improved by introducing the concepts explored in the authors' scenario (**Kanban** and **pull system**), represented in yellow.

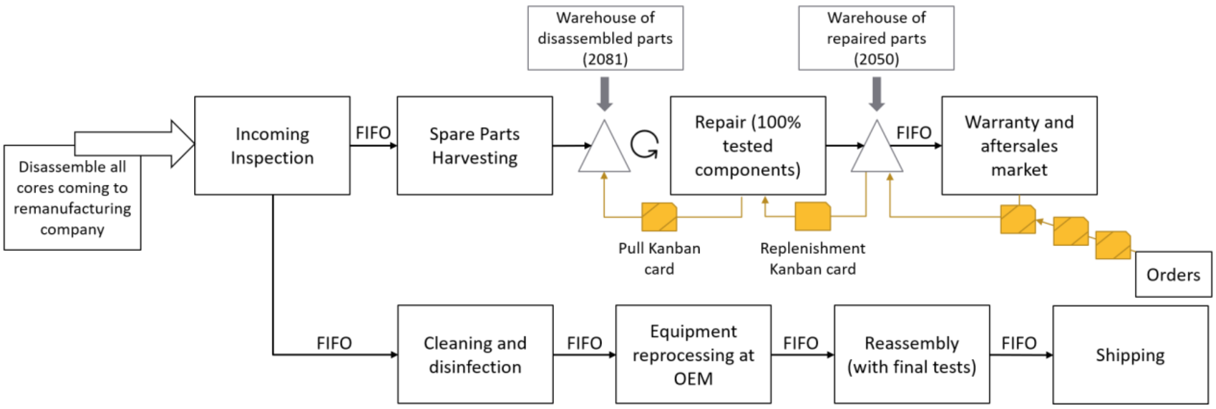

Figure 24. Current and suggested future situation (in yellow) of Siemens Healthineers refurbishment step

Source: Adapted from Kanikuła & Koch (2009).

By implementing lean manufacturing practices in remanufacturing industries, Kanikuła & Koch (2009) expect an improvement in customer service (reduced number of complaints) and lead-time (time between receiving an order and shipping to customer), reduction of stock levels (whether of cores waiting to be disassembled, or of finished products), decrease of value of new parts in remanufactured products, reduced space needed for cores, fast response to customers' orders due to immediate availability of parts in the reassembly process, flexibility to adapt to changing orders, and keeping a supermarket or warehouse for disassembled parts prevents delays in the repair process. Kurilova-Palisaitiene & Sundin (2014), the authors of the MiniMiFa workshop, also implemented a **Kanban system** in the future process map to help stabilizing the manufacturing process, optimize process steps and improve cooperation between customers and suppliers. Successfully implementing this system in the automotive remanufacturer proves that lean principles can be implemented in remanufacturing industries. Additionally, the authors discovered that the lead-time of the process could be reduced by 93%.

The case-study by Pawlik, Ijomah, & Corney (2013) investigated how an automotive remanufacturer has implemented lean manufacturing practices in a shopfloor context, and their impact in the company. Remanufactured products included engines, turbines and turbochargers. Several lean tools, methodologies and practices have been implemented across the facility and are summarized in **Table 13**.

Table 13. Lean tools implemented in the case-study by Pawlik, Ijomah, & Corney (2013), definition and related findings

Lean tool, methodology, practice implemented	Definition	Purpose of use and related findings
Visual Control	According to Liker (2004), visual control is used in the work environment to communicate how work should be done and whether it is deviating from the standard. It also helps employees assess their own performance and to standardize procedures critical to the workflow such as, for example, identify the storage place for work tools. If well designed and implemented, visual control ensures fast and proper execution of operations and processes. Everyday examples include traffic lights and signages.	Used to assist employees in the inspection process by displaying in visual boards sample components and descriptions of critical areas for inspecting and acceptable criteria; empower employees by providing them the tools and knowledge to become more independent to take decisions; communicate and control important metrics, such as TAKT time; focus on quality by displaying the top 10 most common defects.
Pull system	A pull system is triggered by customer demand. In this way, remanufacturing operations are initiated by a signal from the customer (Kurilova-Palisaitiene, 2018), and are only replenished by what the next operation takes away (Liker, 2004).	A pull system was difficult to implement within operations of the automotive remanufacturer due to the high variability and low repeatability of products.
Overall Equipment Effectiveness (OEE)	Used to assess equipment productive time by identifying and measuring losses related to availability, performance and quality rate of the output (Muchiri & Pintelon, 2008). It is to measure the degree to which the asset is doing what it is supposed to do (Williamson, 2006).	Implemented within the whole facility.

Lean tool, methodology, practice implemented	Definition	Purpose of use and related findings
Total Productive Maintenance (TPM)	Method for improving availability of machines by carrying out frequent maintenance and making better use of production resources (Pawlik, Ijomah, & Corney, 2013). The goal is to achieve zero breakdown and zero defects related to equipment, which consequently translates in increased production rates and labour productivity, and reduction in cost and inventory (Muchiri & Pintelon, 2008).	TPM is implemented in critical machines but the objective is to implement in all major machinery.
TAKT time	Time required to complete one job at the pace of customer demand (Liker, 2004). Takt time is behind the lean ideal of one-piece flow: to make one unit at a time with no work in process (WIP) in between operations (Liker (2004), Ali & Deif (2014)).	Hard to use because of the uncertain condition of cores.
5S	A practice to promote and maintain a clean and organized workplace. 5S can be translated as (Chapman, 2005): **S**eiri (sort) - sort needed and unneeded items. **S**eiton (set in order) - define places to put things. **S**eiso (shine) - keep the workspace clean. **S**eiketsu (standardize) - standardize the previous three S's. **S**hitsuke (sustain) - make 5S a routine. 5S is used to support a smooth flow to takt time (Liker, 2004).	Difficult to implement because operations on the various components are carried out at the same workplace, which means there are many different tools at the workstation and not all are required at the same time, however reducing them may cause wastes of motion.
Standard Operating Procedures	Documented procedures that capture "best practice" (Pawlik, Ijomah, & Corney, 2013).	Implemented for all remanufacturing operations.

Source: author by reviewing Pawlik, Ijomah, & Corney (2013).

Dayi, Afsharzadeh, & Mascle (2016) used the 5 lean principles to successfully improve the disassembly process of an aircraft by identifying the best disassembly path. Although an aircraft and a medical system are of different dimensions, the Spare Parts Harvesting process addressed in this dissertation is also a disassembly process, therefore this case-study becomes relevant to analyse. The 5 lean principles are: 1) **identify the value and the value stream**, 2) **eliminate waste**, 3) **create flow**, 4) **respond to customer pull**, and 5) **strive for perfection**. Baring this in mind, the authors analysed the several tasks for disassembling an aircraft and set goals according to the characteristics of the observed challenges. The first characteristic is the large dimension of an airplane, which makes disassembly more complex because there are several working areas around the aircraft and some technical operations are performed simultaneously. One goal is therefore to **minimize changing working zones and displacements** and **maximize the number of executed tasks** in that working zone. The sequence of tasks and subtasks to disassemble a given part *i* was optimized using MATLAB. With this, the authors could create a disassembly graph identifying the several areas of the aircraft one must go through to disassemble the given part *i*. Repeating the process for all parts, the authors were able to find common tasks. Naturally, different options of routes/paths emerged and this was where lean principles could also be applied: finding the best path supposes **eliminating waste** by **reducing disassembly time and delays**, a **continuous flow** by choosing the optimal sequence for disassembling parts and considering the different airplane zones, and a **high level of efficiency and quality** taking into account various parameters of reverse supply chain. Therefore, the authors conclude that the integration of lean principles improves the efficiency of the disassembly process.

Kurilova-Palisaitiene (2018) identified several lean tools and practices that could be used to target a specific improvement. The author identifies **standard operating procedures**, **5S**, **visual management**, **value stream mapping** and **spaghetti diagram** to achieve improvements in quality management; **product families** and **layout for continuous flow** for improvements in process and layout; **FIFO** (First In First Out) **lanes** for improvements in operations planning and scheduling; **PDCA** (Plan, Do, Check, Act) for continuous improvement; **supervision and mentorship** for improving employee commitment and management; among many others. It is worth mentioning that product families are already in use in the Spare Parts Harvesting process, because the process addressed in this dissertation handles exclusively Advanced Therapies (AT) systems. On the other hand, the other workshop in charge of harvesting parts from the other business area (Diagnostic Imaging (DI)) does not separate incoming systems (XP, CT, MR) in product families, instead, they are all processed in the same area and simultaneously. This process could be improved if systems were first separated and handled in product families. FIFO is also employed in the Simon Hegele Refurbishing Centre: systems that arrive first, are handled first.

To conclude, the implementation of lean in a remanufacturing context has several benefits, which include reduction of lead-time, work in process, overproduction, inventory, setup time, motion and waiting time wastes, floor space, and on the other hand improvement of quality and on-time shipments, result of the identification and elimination of non-value-added activities through continuous improvement (Vasanthakumar, Vinodh, & Vishal (2017), Pawlik, Ijomah, & Corney (2013)).

It was seen in the previous section 3.1., that among the product recovery management options, the Spare Parts Harvesting process analysed in this dissertation is classified as cannibalization, according to Thierry, Salomon, Van Nunen, & Van Wassenhove (1995). The Google Scholar search tool was used to conduct this literature review, and several combinations of key words were tried in order to reach scientific papers on that theme. However, no combination led to a paper addressing both “cannibalization” (or others that were tried) and “lean” keywords. Therefore, it is concluded that there is no scientific support on this area, constituting a good research opportunity.

3.4. Chapter Conclusions

In this chapter, the relevant literature to support concepts and terms used throughout the dissertation was examined. Different solutions for end-of-life products were presented, introducing the concept of product recovery management (PRM). An ambiguity concerning the terms repair, remanufacturing and refurbishing, but mainly between the last two, was identified and clarified for the purpose of the case-study. Then, the relevance of a spare parts business and the challenges in spare parts inventory management were investigated. It was possible to verify that the challenges identified in the literature review are confirmed in practice, once these were also reported by Siemens Healthineers, such as forecasting demand for parts having in consideration the life cycle of the product. Afterwards, lean thinking was introduced. From the Toyota Production System many teachings can be learned, among them many powerful tools, methodologies and practices and that were examined for the context of this dissertation. Moreover, it was possible to understand that more and more research is being developed towards the implementation of lean in remanufacturing processes. Some challenges this particular industry faces were identified, as several studies point out to the conclusion that implementing lean in remanufacturing companies constitutes a bigger challenge than in manufacturing companies, mainly due to the high uncertainty involved in the incoming cores in terms of quality, quantity and timing. Moreover, products are increasingly more varied, which makes remanufacturing even more challenging. Nevertheless, remanufacturing is compatible with lean production practices and its implementation generates economic advantages that help companies improve their competitiveness (Rubio & Corominas, 2008). Concerning the specific process of Spare Parts Harvesting, a gap was identified in the literature as no case-studies addressing this specific topic were found.

4. Methodological approach and obtained results

The present chapter 4. is structured as follows: in section 4.1., the overall methodological approach followed to improve the Spare Parts Harvesting process is presented, followed by section 4.2. where it is explained how the challenges were identified, and section 4.3. where the description of the process improvement itself takes place, resorting to lean tools, methodologies and practices identified in the previous chapter 3.; in section 4.4., the achieved results are discussed; and in section 4.5., the main conclusions of the chapter are summarized. Taking into account the nature of the problem, the methodologies employed and in order to avoid too many redundancies and repetitions in this document, it was decided to present the methodology and results obtained in the same chapter of the dissertation.

4.1. Overall methodology

In this section, the work methodology followed for the implementation of lean in the Spare Parts Harvesting process is described and illustrated in **Figure 25** (based on the work of Kurilova-Palisaitiene (2018)).

During the development of the present dissertation, which included a 6-month stay at the company between February and July 2020, there were essentially 3 distinct steps. The first step had to do with preparation, that is, to collect and systematize information on the 5-Step Quality Process to refurbish an end-of-life medical system, and especially on the Refurbishment step with focus on the Spare Parts Harvesting process. To accomplish that, five data collection methods were carried out, based on the work of Sundin (2006) and Kurilova-Palisaitiene (2018), process that is called “triangulation”: manager interviews were essential to survey the challenges and issues across the several processes, as well to establish strategic goals; observation of shop floor operations allowed to understand how the processes work in practice; personnel interviews highlighted the problems at the operational level; brainstorming meetings were fundamental to establish feasible goals and prioritize improvement ideas; and literature review provided the theoretical background needed to decide which lean tools, methodologies and practices best suit the characteristics of the present case-study. The preparation step provided all the necessary inputs to the execution step. This second step started with the process mapping (first point in the execution step, detailed in section 4.2.1.), with the objective of identifying all material and information flows in the Simon Hegele Refurbishing Centre and in the Spare Parts Harvesting process, in order to gather a visual representation of the process and which allows to discover problems and improvement opportunities more easily. Then, a root-cause analysis (second point in the execution step, detailed in section 4.2.2.) was performed, which aimed at identifying what was causing the low productivity in the Spare Parts Harvesting process. Carrying out these first two steps, the conditions were gathered to effectively identity the process challenges’ and improvement opportunities (third step in the execution step, summarized in section 4.2.3.). Finally, supported by literature review, the selected lean tools, methodologies and practices were implemented in order to optimize the Spare Parts Harvesting process (fourth step of the execution step, detailed in sections 4.3.1. and 4.3.2.). The last step concerned with data collection to assess the impact of the improvement in the process and was carried out through the delivery of a questionnaire to the Spare Parts Harvesting workers and by observing and analysing the improved process.

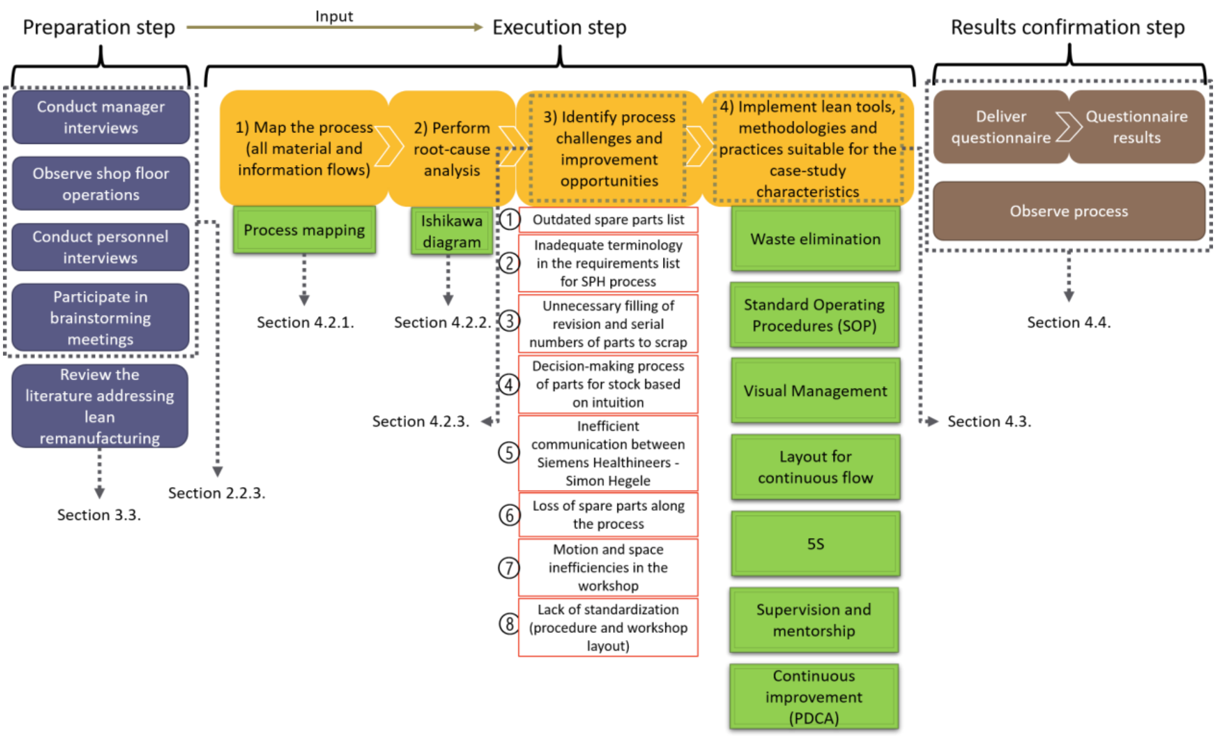

Figure 25. Methodology followed for lean implementation in the Spare Parts Harvesting process, based on Kurilova-Palisaitiene (2018)

4.2. Identified challenges and selected lean tools based on literature review

The first step to any problem-solving methodology is to identify the problems and what is causing them (the root-causes), in order to proceed to corrective measures that allow to achieve the desired outcome. A problem, in the words of Dennis (2007), "is a deviation from a standard, that is, a difference between what should be happening and what's actually happening". This section focuses on the first three points of the execution step: 1) map the process, 2) perform root-cause analysis and 3) identify process challenges and improvement opportunities. It is therefore divided into 3 subsections, dedicated to the analysis of each of these points.

4.2.1. Process mapping

By reviewing the literature, it was seen that process mapping and spaghetti diagramming are suitable tools for identifying non-value-added activities in the process, in the way they describe the material and information flows along the value stream (Liker (2004), Melton (2005), Sundin (2006)). Mapping the process by designing it is part of a **visual management practice** and one of the steps in the MiniMiFa workshop by Kurilova-Palisaitiene & Sundin (2014). Although this workshop was not carried out, its ideas were retained and adapted to the current situation. Three maps were developed as part of the first point of the execution step (**Figure 25**), one to study the material flow in the Simon Hegele Refurbishing Centre (Appendix A), which originates the respective spaghetti diagram (Appendix B), and another to study, mainly, the information flow in the Spare Parts Harvesting process, illustrated in **Figure 26**.

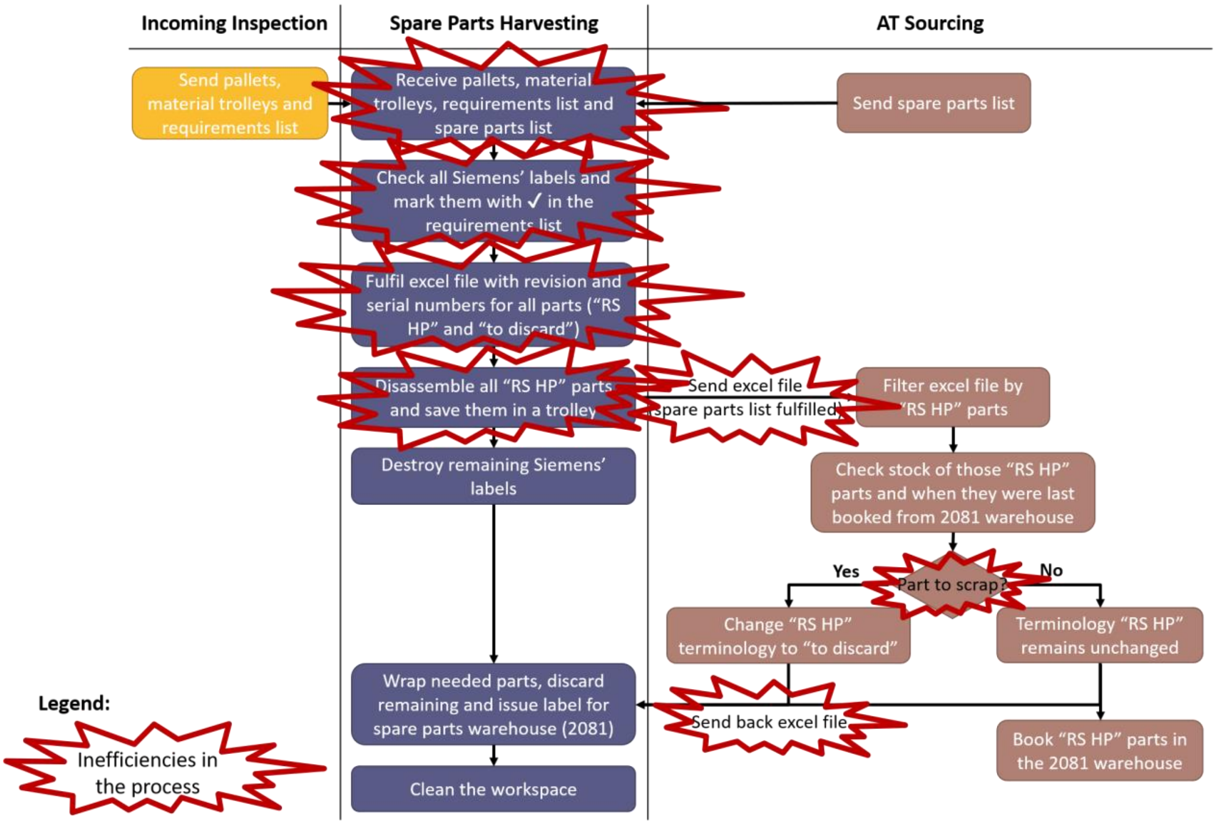

Figure 26. Spare Parts Harvesting process map

The red "stars" identify inefficiencies in the information flow. The first red star highlights the receiving of pallets, material trolleys and the lists in the SPH process because the pallets are placed randomly inside, leaving the workshop poorly organized and creating motion wastes, and the lists (as it has been seen throughout the dissertation) are outdated and inadequate to the process, making the searching for the parts much more difficult. The second red start highlights the checking of all Siemens' labels and signalize them in the requirements list because this is a non-value-added activity which consumes a lot of time, and could be greatly improved if the spare parts list was shorter and the requirements list different. The third red star highlights the fulfilling of the excel file with the revision and serial numbers for all parts found inside the system (both "RS HP" - Refurbished Systems Harvested Parts - parts and "to discard" parts), which again is a non-value-added activity (and therefore a waste) because the parts identified as to scrap are filtered and ignored in the following operations. The fourth and fifth red stars are interconnected because if the spare parts list was up to date, the SPH workers would disassemble the identified RS HP parts knowing these are parts truly needed for stock (versus the current situation in which a part identified as RS HP can actually be a part to scrap, but nevertheless the worker still wastes time disassembly them all), and it wouldn't be necessary to send the excel file fully filled to later receive the confirmation of which of those RS HP parts are actually to save. The following red star has to do with the decision-making process of whether or not a RS HP part should be scrapped, which currently is made based on intuition even though there is a file that states what should be the minimum and maximum quantities to keep of each part-number. The last red star highlights the moment when Siemens Healthineers sends back to the SPH workers the excel file they first sent, identifying the parts (already disassembled) that are needed for stock. This could be avoided if the spare parts list was updated and identifying right away all the parts needed for stock in a given period of time.

In section 4.2.3., lean tools, methodologies and practices to overcome these inefficiencies are identified based on literature review.

4.2.2. Root-cause analysis

The root-cause analysis was developed resorting to an Ishikawa diagram in order to investigate the real motives why the problem is happening and is part of the second point of the execution step. The Ishikawa or cause-and-effect diagram was selected based on literature review (Ishikawa (1976), Pawlik, Ijomah, & Corney (2013)) and the result is illustrated in **Figure 27**, where five main problem categories were identified as impacting the current low productivity in the SPH process: method, machine, manpower, material and environment.

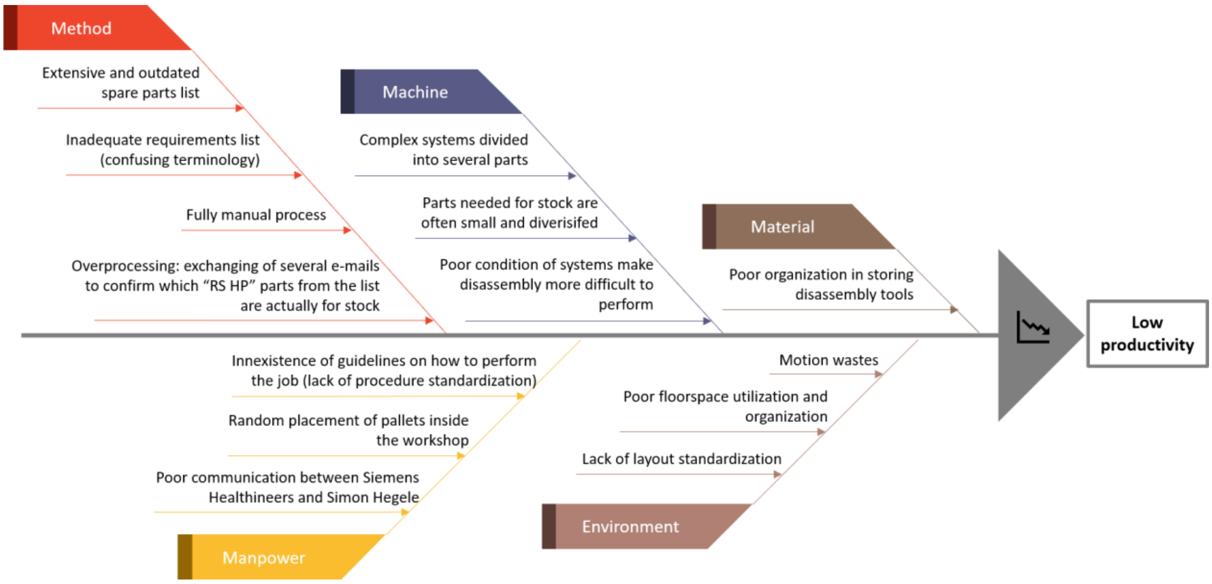

Figure 27. Root-cause analysis of the low productivity in the SPH process using the Ishikawa diagram tool

The method category concerns with all problems affecting how the process is carried out: the spare parts list, the requirements lists, the fact that is a fully manual process and the overprocessing of e-mails also identified in the process map in **Figure 26**. The machine category has to do with the systems received in the SPH process: these are complex systems, divided into several parts (main parts and others), they often come in bad conditions which makes handling more difficult, and the parts needed for stock are often small and inside the main parts, being necessary to look for them among many diversified parts. The material category refers to the tools used by the SPH workers to disassemble the parts, and which could be better organized and stored in specific places. Manpower category is related to the people involved in the SPH process, mainly the SPH workers but also Siemens Healthineers, in what concerns communication. As for the environment category, this has to do with the workshop where the process is performed, and refers to the lack of layout standardization, poor floorspace utilization and motion wastes perceived because of the random placement of pallets inside.

4.2.3. Challenges and opportunities

Having completed the process mapping and the root-cause analysis (the first two points of the execution step), the conditions are now gathered to revisit and formalize the main challenges in the Spare Parts Harvesting process and relate lean improvements based on literature review. From the process map in **Figure 26**, inefficiencies regarding the information flow were perceived and have to do mainly with the lists used in the process and the way information is exchanged between Siemens Healthineers and Simon Hegele. Then, with the Ishikawa diagram, the causes for the low productivity in the process were identified. In the end, a total of eight problems were perceived (already highlighted during section 2.2.3.) and are now summarized in **Table 14**.

Table 14. Summary of identified problems in the Spare Parts Harvesting process and suggested improvements

Identified challenge	Description	Related lean improvement based on literature review
(1) Outdated spare parts list	The list has not been updated for at least 4 years, when the previous manager responsible for the process retired. This results in a long list of 2,011 part-numbers, many of which should no longer be harvested, and others that should be but as they are not in the list, are lost in the process (scrapped).	Update the list resorting to the master data pool file from CS: eliminate parts not needed for stock and introduce those which are needed and therefore should be harvested (**eliminate wastes**). Create a **standard operating procedure** (SPO) where the list must be updated every month by the AT Sourcing department, specifically the ecoline team.
(2) Inadequate requirements list for Spare Parts Harvesting process	The list was created to facilitate the incoming inspection process and from then on was sent to the SPH to also assist in the process. This list uses terminology such as “not relevant” to indicate those parts received in the Incoming Inspection that are not used for ecoline systems, and therefore can be ignored and sent immediately to the SPH. However, even if a part is not relevant for the incoming inspection, it might refer to a part that is relevant for harvesting. The process is then susceptible to creating mistakes when the SPH worker receives the list with that indication.	Improve the list by eliminating confusing terminology and adapt it to the SPH process (**identify value-adding and non-value-adding items and eliminate the latter**).
(3) Unnecessary filling of serial and revision numbers in the spare parts list	Currently, the SPH workers fill in all serial and revision numbers for all the parts found in the systems received (whether it is a part to scrap or to harvest). This results in an unnecessary operation and an extremely time-consuming task, because the parts identified to scrap are overlooked along the entire process (no one will check these parts’ revision and serial numbers).	Eliminate unnecessary tasks with non-value-added to the process (**eliminate wastes**).

Identified challenge	Description	Related lean improvement based on literature review
(4) Decision to stock RS HP parts is done based on intuition	When the Siemens Healthineers worker receives the spare parts list fulfilled from the SPH process, he filters the excel file to show only those parts marked with RS HP (Refurbished Systems Harvested Parts, terminology used to identify parts needed for stock) and next checks when were those parts last booked and quantities. Based on intuition, he decides whether is necessary to keep stock of those parts or not.	Improve the decision-making process which should not be based on intuition but should be done resorting to the master data pool file, which specifies the min-max references for every part-number inventory (define this as a **SOP**).
(5) Inefficient communication between Siemens Healthineers – Simon Hegele	In the current state, Siemens Healthineers sends the spare parts list to the SPH workers, which after fulfilled is sent back. Then, Siemens Healthineers checks the parts identified with RS HP in SAP to decide if it is actually a part needed for stock; if not, RS HP is changed to "to scrap" and the list is sent again. The result is an inefficient communication between the two parties, with an excessive exchange of e-mails, complicating the whole process. Moreover, the SPH workers disassemble all RS HP parts before sending the fulfilled list, and which in turn might be a part identified as "to scrap", resulting in an unnecessary operation.	Eliminate the exchange of two e-mails between Siemens Healthineers – Simon Hegele, having SO department sending only one identifying straight away the parts from that system that are needed for stock. This would also prevent SPH workers having to disassemble all RS HP parts, instead disassembling only the actually needed parts identified in the "one" e-mail (**elimination of a non-value-added activity and time and space wastes**).
(6) Spare parts lost along the process	This problem is a result of the outdated spare parts list, because CS is requiring parts (identifying them in the master data pool file) but as the list is not updated, these do not enter the spare parts list and therefore no one knows those parts are needed and are overlooked, ending up in scrap.	Update and improve the spare parts list.
(7) Motion and space inefficiencies	The SPH workers bring the pallets into the workshop and place them randomly inside. As usually one system is divided by several pallets and they cannot all be placed inside at the same time (space constraint), this means they enter and exit with pallets several times. It was observed that sometimes they have to move some pallets out of the way to be able to take in or out another pallet, resulting in wastes of motion.	**Rearrange process layout** in order to allow **for a continuous flow (third lean principle)**. Organize the workshop resorting to **5S** methodology to eliminate/reduce motion and space wastes.
(8) Lack of standardization	The overall process lacks standardization, whether in the work procedure or in the workshop layout. The workers do not have guidelines to perform their job and simply do what and how they think it is best.	Create **Standard Operating Procedures (SOP)** for the whole process, by establishing a uniform and clear work procedure, as well predefine areas to leave the pallets inside the workshop by resorting, e.g., to signalization (**visual control**).

The objective is to improve the Spare Parts Harvesting process by completely reviewing and restructuring work process, as well as rearranging the workshop, by resorting to lean methodologies, tools and practices identified earlier in chapter 3.. Besides those already identified in **Table 14**, other lean practices will be implemented, such as **supervision and mentorship** to teach the SPH workers the new work procedure, and **continuous improvement** (resorting to **PDCA cycle**) as part of the **fifth lean principle – pursuit perfection**.

4.3. Spare Parts Harvesting process improvement

This section focuses on the implementation of the selected lean methodologies, tools and practices reviewed in chapter 3., and concerns with the fourth point of the execution step (**Figure 25**). It is divided in two other subsections, one addressing the improvement and standardization of the SPH work procedure (4.3.1.) and which concerns with the implementation of standard operating procedures (SOP) and eliminating wastes in the lists, and the other addressing the improvement and standardization of the workshop layout (4.3.2.) and which concerns with the implementation of visual management tools (visual control), 5S, and layout for continuous flow. Supervision and mentorship are used in both subsections because it is not possible to achieve process improvement without training the workers to it.

4.3.1. Work procedure improvement and standardization

It has been seen that there are essentially two major problems in the Spare Parts Harvesting process, one regarding the work procedure and the other regarding the workshop layout. This section focuses on the improvement and standardization of the work procedure, which started by reformulating the lists currently used to assist in the process (4.3.1.1.), which led to the creation of new lists overviewed in 4.3.1.2., and which finally allowed creating and establishing Standard Operating Procedures for the Spare Parts Harvesting process (4.3.1.3.).

4.3.1.1. Lists reformulation

- **Spare parts list**

One of the most significant steps towards lean in the Spare Parts Harvesting process is standardization. The entire process lacks guidelines of what to do and how. If in any eventuality the SPH workers had to be replaced, the following people would have no idea what the process is about – it lacks structure. It is therefore essential to create **Standard Operating Procedures (SOP)** (Pawlik, Ijomah, & Corney (2013), Kurilova-Palisaitiene (2018)). To accomplish that, the whole process was reformulated and restructured, starting with the spare parts list.

The planning of a new list had the input of the AT Sourcing (SO) department (specifically, the AT ecoline team), the Customer Service (CS) department in Erlangen, and the Installed Base Development (IBD) department. The first stage to improve the spare parts list was to update it, resorting to the master data pool file. To do so, the data pool file was filtered to only show only AT systems. From the initially 4,399 part-numbers present on the data pool file, 452 belong to AT systems. Then, another filter was applied, this time to show only those part-numbers which are needed between the time period “now – in 39.12 months”; this was established as a good inventory period to account for volatile demands while not incurring in high inventory costs. The result was now 168 part-numbers. From these, the technical engineer checked all one by one where that part-number can be found, that is, inside which system's main parts. It might happen that one spare part can be found inside several main parts from distinct systems. For an example, let's consider **Table 15**: the spare part-number 875200 refers to a monitor that can be found inside three different systems, the Artis One 123, the Artis Pheno 456, and the Artis T 789. The technical engineer proceeded to this check-up for all the 168 part-numbers and the result was the following **Table 15**. For clarity, the part-number from the data pool needed for harvesting will be denoted spare part-number.

Table 15. Locating spare part-numbers within main parts

Spare part-number ↓	Description ↓	Where that part-number can be found (inside/belonging to this main part) ↓
875200	Monitor	Artis One 123 / Artis Pheno 456 / Artis T 789
457812	ABC spare part	Artis Pheno 456 / Generator 190 / Generator 250
014628	Detector	Artis T 789
3458	GHI spare part	Arcadis
47823	JKL spare part	Arcadis

This list was then reorganized to show for each main part, which spare part-numbers are inside, as illustrated in **Table 16**. Like this, upon receiving the several main parts in the SPH workshop, the SPH workers can consult this list and identify immediately which spare parts they need to harvest from those main parts, **ignoring all the other part-numbers they find** inside them.

Table 16. Example of the Spare parts catalogue

Main part	Main part number	Spare part number	Description
Artis One	123	875200	Monitor
Artis Pheno	456	875200	Monitor
		457812	ABC spare part
Artis T	789	875200	Monitor
		014628	Detector
Generator	190	457812	ABC spare part
Generator	250	457812	ABC spare part
Arcadis		3458	GHI spare part
		47823	JKL spare part

This new organized list was designated "**spare parts catalogue**", as in the end it worked like a catalogue for consultation. So, for example, when receiving an Arcadis system (with no specific part-number, so any Arcadis system in general), by looking to the catalogue they immediately know they only need to look inside for the parts with the numbers 3458 and 47823, ignoring all the remaining ones. It might happen that they find both parts or just one of them; either way, the parts must be disassembled as these are the spare parts needed for stock.

This represents already a drastic change to the old process, because before the workers had to disassemble all parts identified by RS HP without possessing the information whether that part was currently needed for stock or not and received the confirmation by exchanging an e-mail with the AT Sourcing (SO) department, which could take several days. With this catalogue, the non-value-added activities of first disassembling all RS HP parts and then receiving the confirmation of which of those parts are needed for spare parts via e-mail are **eliminated**, significantly impacting the lead-time for harvesting a system. The previous spare part list with the 2,011 part-numbers was replaced by this new spare parts catalogue.

As it was mentioned earlier, the data pool file was filtered to show the part-numbers needed between the time period "now – in 39.12 months". Therefore, it was established that every new month the spare parts catalogue must be updated resorting to the data pool file.

- **Requirements list and (new) cross-check list**

Next, it was necessary to improve the requirements list from the incoming inspection. A new column was added to identify which parts from that list are spare parts, making it easier for the SPH workers to identify the part-numbers they have to search on the main parts they receive. To do so, a new list had to be created, the cross-check list. This list is nothing less than a copy of all main part-numbers and spare part-numbers from the spare parts catalogue pasted into a single column (it is not relevant to separate them). Then, in the new added column in the requirements list, a formula is written in order to mark with "X" if there is a match between the part-number present in this list and the part-number in the cross-check list – this allows to automatically know that that system contains x parts which are or contain spare parts. Similarly, the cross-check list must also be updated every month after updating the spare parts catalogue. **Table 17** illustrates the new requirements list, where the green column represents the new-added column (for comparison with the old list, check **Table 8**). In the old list, the worker would need to check if part-numbers 789 and 112 were spare parts in the spare parts list (identified as RS HP); now, the column "spare part" identifies automatically part-numbers that are needed for spare parts with an "X", by resorting to the cross-check list. The worker must ignore the column "not relevant" as this information is only necessary for the Incoming Inspection.

Table 17. Example of the new requirements list

In the requirements list	In the TD list	Part no.	Serial no.	Description	Not relevant	Present	Not present	Spare part	Comment
		123[1]	123ABC	Software	X				To scrap
X		456[1]	456DEF	Table		X			To refurbish
		789[2]	789GHI	Detector		X		X	
	X	112[2]	112JKL	Circuit board	X			X	
	X	113[1]	113MNO	Protection			X		

1) The worker does not need to search for this part no. on the excel file to confirm if they are spare parts or not as they are identified that one has already gone to scrap, the other went to refurbishing and the other was not received in Forchheim.

2) With the current requirements list, the workers know these two part-numbers are needed for stock.

- **Disassembly list (new)**

Finally, a new excel sheet was created for the SPH workers, designated "disassembly list". In this list, they only need to copy, for every system, the spare part numbers of the spare parts catalogue which were disassembled from the parts received, and **filling only on those the respective revision and serial number** (in contrast to having to fill in for every single part-number they found on the main parts, whether it was a part to scrap or not). In the new improved process, the SPH workers receive the spare parts catalogue updated every month, and for each system that will enter the SPH process, they receive a single excel file with 3 lists (excel sheets) inside: the requirements list, which previously they only received in paper from the incoming inspection, the cross-check list which is used to automatically identify in the requirements list the parts to harvest, and the disassembly list. By receiving the requirements list in excel, they can further improve their job by filtering the list to show only those cells containing the "X" mark, indicating that these are the ones that are spare parts (instead of marking by hand with "✓" in the requirements list **all** the part-numbers they found on the main parts received, so that they could then introduce in the old spare parts list the revision and serial number and disassemble them all). From the around 100 part-numbers on the requirements list, only around 10 part-numbers are spare parts, so if they filter the list they can print this short version out and greatly improve their productivity. After disassembling the spare parts, they must fulfil the disassembly list, illustrated in **Table 18**, and send it back to SO which can then proceed to the booking of those parts in the 2081 warehouse. The system is closed and the process concluded.

Table 18. Example of the disassembly list

System: Artis Pheno				
Material short description	Parts retrieved (part-number)	Serial no.	Revision no.	Remark

4.3.1.2. Lists overview

In this section, a summary of the lists used in both the old and new SPH process is provided in **Table 19**: the old spare parts list is now designated spare parts catalogue; the requirements lists was reformulated to include a column identifying automatically which part-numbers on the list are part-numbers needed for harvesting; the cross-check list didn't exist in the old process and is used only to identify automatically the part-numbers on the requirements list which are needed for spare parts; the disassembly list used to be part of the old spare parts list (the SPH workers would fill in the spare parts list all revision and serial numbers for all the part-numbers found inside the system, corresponding to a sort of disassembly list), but now this is a separate list in which the workers only need to fill in all the information from a RS HP part disassembled from the system (name, part-number, revision number, serial number) and which is effectively a part needed for stock (since the spare parts list is updated).

Table 19. Overview of the lists used in the SPH process before and after improvement

List name	Old process	New process
Spare parts list	- Extensive list of 2,011 parts identifying which parts are needed for spare parts stock (RS HP parts); outdated since 2016, it contained parts no longer being harvested and new parts that should be harvested were not on the list.	- The list is now called spare parts catalogue and identifies for each main part, all the spare parts that can be found inside; it is updated every month by the AT ecoline team.
Requirements list	- List used in the incoming inspection to identify parts that will be used in new ecoline systems.	- List used in the incoming inspection to identify parts that will be used in new ecoline systems; - List used in the SPH process to identify all the parts needed for harvesting.
Cross-check list	- This list didn't exist.	- The cross-check list was created to automatically identify in the requirements list (used in the incoming inspection) those parts that are spare parts.
Disassembly list	- The list didn't exist. The SPH workers filled in the old spare parts list the correspondent revision and serial numbers for all part-numbers they would find on the main parts and send it to SO.	- This is a new list used to identify only those parts that were disassembled in the SPH process. When sent to SO, these parts are immediately booked in the 2081 warehouse without further processing.

4.3.1.3. Establishing Standard Operating Procedures for the Spare Parts Harvesting process

After almost 3 months of developing the new excel file with the three lists inside (requirements list, cross-check list and disassembly list), it was time to test their applicability. First, all the new lists and the new process were carefully and thoroughly explained to the SPH workers. Then, the workers were asked to try themselves the new lists and to find some of the part-numbers marked as spare parts. They were incredulous that they didn't have to look at all the Siemens' labels inside the parts received, but just had to search for the part-numbers already marked on the requirements list – in fact, they asked several times if this was really the procedure and if they could scrap immediately the remaining labels without first confirming with Siemens Healthineers (this was the old procedure, when they awaited the confirmation on the parts to save or to scrap to arrive via the second e-mail). They had to be tranquilized that this was the new procedure and that it was ok to do so. As they searched for the marked part-numbers in the requirements list, it was verified that **at least two new spare parts were never harvested before** – this is due to the fact that the list they used to work with (the old spare parts list with the 2,011 part-numbers) was completely outdated. So, through all this time the list was last updated (probably around 4 years ago), one can only speculate on the number of spare parts that were lost in the process. By updating the cross-check list and the spare parts catalogue every month, this is avoided. The test was successful and both parties (Siemens Healthineers supervisors and Simon Hegele workers) were very satisfied with the new established procedures (SOP), which finally marks the beginning of a standardized process in the Spare Parts Harvesting. It can now be presented the new Spare Parts Harvesting process map, representing the **Standard**

Operating Procedure for the SPH process, illustrated in **Figure 28** (for comparison with the old process, check **Figure 26**). Although it seems more complex, information flows are optimized.

It is also worth mentioning that before, the Simon Hegele workers at the SPH process had no access to the weekly planning of incoming systems for harvesting, that is, the plan that states how many systems and which systems will enter the Spare Parts Harvesting process in each week. This was done by Siemens Healthineers and the information was not passed. Now, the weekly planning of incoming systems is also sent in the same e-mail as the 3 lists, which allows them to plan ahead the work week, how to organize the workshop and allocate resources as needed. For example, if in week *n* they know they will only receive 2 monoplane systems, then one SPH worker is enough to perform the job, leaving the other available to support some operation elsewhere; but if in week *n+1* they receive 1 biplane system and 3 monoplane systems, they can warn in advance that that week they will need extra help from one or two other workers. The improvement of the SPH work procedure used the notions of the **5 lean principles**, particularly principles 1, 2 and 3 (identify the value and the value stream, eliminate waste and create flow).

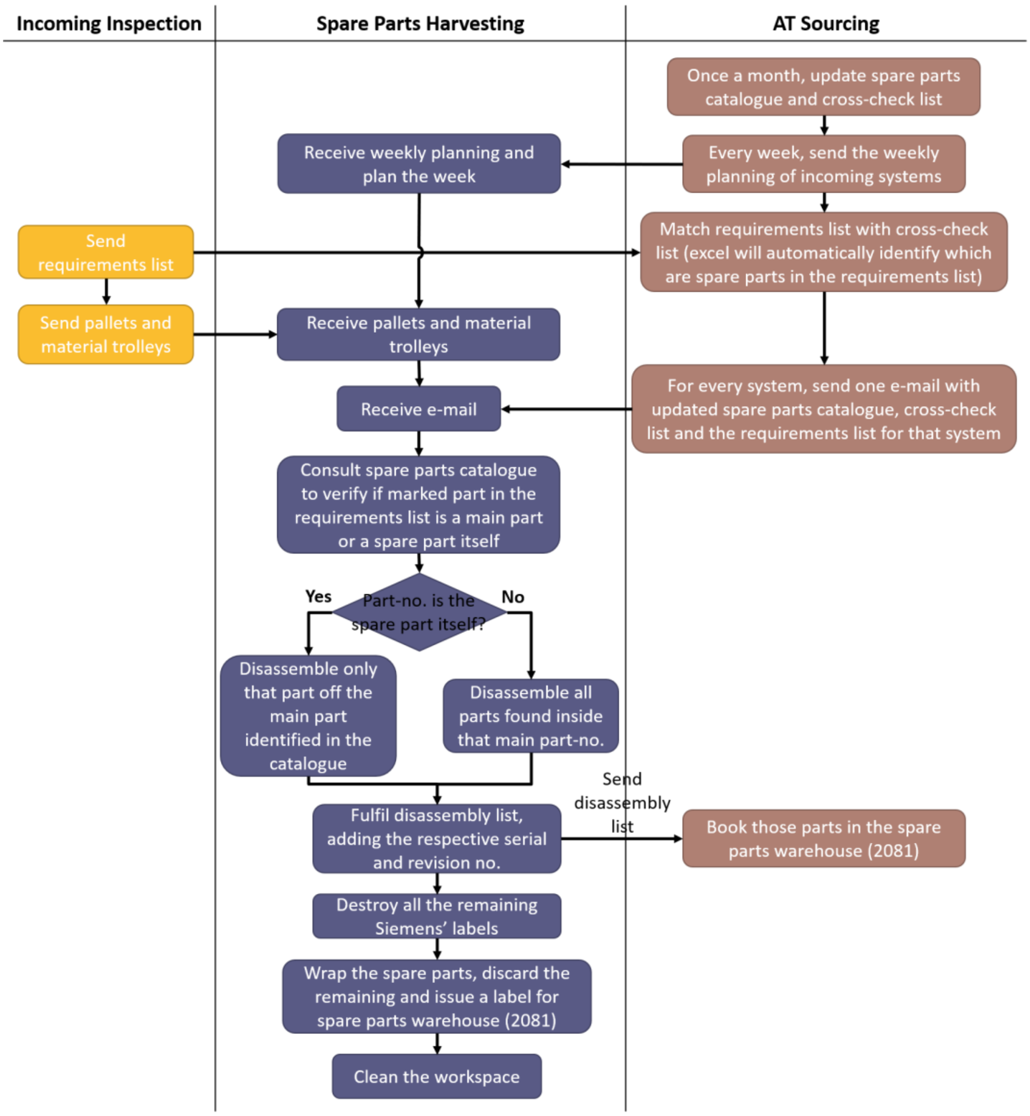

Figure 28. New Spare Parts Harvesting process map with identification of responsibilities of each department

4.3.2. Layout improvement and standardization

One of the major identified problems in the SPH process was the poor organization of the workshop, creating wastes of motion, impacting the productivity of the workers and consequently increasing process lead-time (recall **Figure 13**, **Figure 14**, **Figure 15** and **Figure 16**). To achieve improvements at this level, it was necessary to study the workshop and understand how the layout could be changed. To do so, first a capacity study and a material flow analysis inside the workshop was carried out (in section 4.3.2.1.) to allow the development of layout suggestions (in section 4.3.2.2.), and the selection of the best option (in section 4.3.2.3.).

4.3.2.1. Capacity and material flows analysis

The SPH for AT systems is an area of 100 m^2. Inside, the challenge is to rearrange the layout in order to achieve a smooth and continuous flow when bringing in and taking out the pallets, like the results evidenced by the case-studies reviewed in chapter 3. (Östlin & Ekholm (2007), Kanikuła & Koch (2009), Pawlik, Ijomah, & Corney (2013), Dayi, Afsharzadeh, & Mascle (2016), Kurilova-Palisaitiene (2018)). A capacity study was carried out to find out the average number of pallets and material trolleys that can be expected for each system (monoplane and biplane). Through **Table 20** one can see that per monoplane system are expected between 6-8 pallets and 1-2 material trolleys, and per biplane system are expected between 8-12 pallets and 2-3 material trolleys. As for the workforce, there are currently 2 workers harvesting parts for AT systems and usually each worker handles one system, which makes a total of 2 systems being harvested at a time.

Table 20. Capacity study per single AT system received

Capacity study			
	Pallets	Material trolleys	Human Resources
Monoplane system	6-8	1-2	2 (usually each worker handles one system at a time)
Biplane system	8-12	2-3	

Taking this into account, **Table 21** presents the possible combinations of every 2 systems that can be received in the area: the most common situation is 2 monoplane systems at a time, which translates in an average of 14 pallets and 3 material trolleys awaiting harvesting; it can also happen that one worker is handling 1 monoplane system and the other 1 biplane system – in this situation, the average quantity of pallets is 17 and of material trolleys is 4; finally, a rare situation is receiving 2 biplane systems at the same time for harvesting, which makes an average of 20 pallets and 5 material trolleys in the "worst case scenario".

Table 21. Capacity study per possible combinations of AT systems received

Possible combinations					
				Capacity study	
				Pallets	Trolleys
Often	2x Monoplane			12-16 (**~14**)	2-4 (**~3**)
Sometimes		1x Monoplane 1x Biplane		14-20 (**~17**)	3-5 (**~4**)
Rarely			2x Biplane	16-24 (**~20**)	4-6 (**~5**)

So, as it is possible to conclude, there can be up to 24 pallets at a time in the 100 m^2 area. As it is not possible to place this many pallets inside, the challenge is to organize the area in order to allow the SPH workers to efficiently bring in and take out the pallets as they check for spare parts, eliminating or reducing the wastes of motion that will be seen in the following section 4.3.2.2..

4.3.2.2. Layouts development

The following step was to develop the current layout status, illustrated in **Figure 29**, to visually identify challenges and improvement opportunities (once again, lean visual management tool is used).

By developing this layout, the challenges with this (non-)organization become obvious:

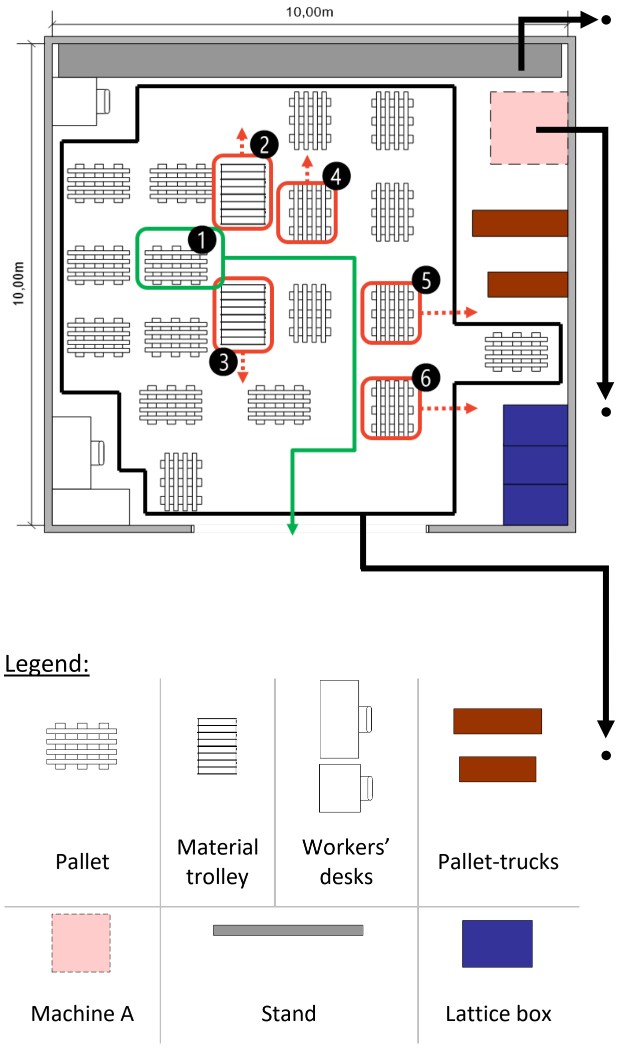

Figure 29. Before SPH layout and material flow analysis

- The stand at the back of the room is currently rarely used to support ongoing activities. In fact, the stand itself lacks organization. This was perceived as a huge waste of useful storage and operational space, as workers could use it to place the smaller parts that come in the material trolleys to inspect them and destroy the Siemens' labels of the parts to scrap.
- Another big inefficiency is related to a big machine stored in this area, from now on designated machine A, which has nothing to do with the process and is simply stored there because there was no other place to put it, according to Simon Hegele supervisors. The machine occupies a large area of useful space and it should be removed.
- As it can be seen, the pallets and material trolleys are left scattered randomly around the room. Considering the example that a worker wanted to take out pallet 1, it was observed that it was necessary to move material trolleys 2 and 3, and pallets 5 and 6 first out of the way, creating wastes of motion and impacting productivity with this non-value-added processing activity (increasing process lead-time).
- Finally, the workshop lacks a standardized configuration to place the pallets and material trolleys. The workers leave them wherever they want because there is no indication to perform otherwise. They do not have a standard/predefined configuration to efficiently use the available space (there are no Standard Operating Procedures).

With the findings from the literature review in mind, two layout suggestions were developed considering lean methodologies 5S, Visual Management tools (specifically Visual Control) and Layout for Continuous Flow (Östlin & Ekholm (2007), Kanikuła & Koch (2009), Pawlik, Ijomah, & Corney (2013), Dayi, Afsharzadeh, & Mascle (2016), Kurilova-Palisaitiene (2018)), illustrated in **Figure 30** and **Figure 31**. A material flow study was also developed for both layouts and can be consulted in Appendix C and Appendix D, which allowed to assess the pros and cons of each, presented in **Table 22**.

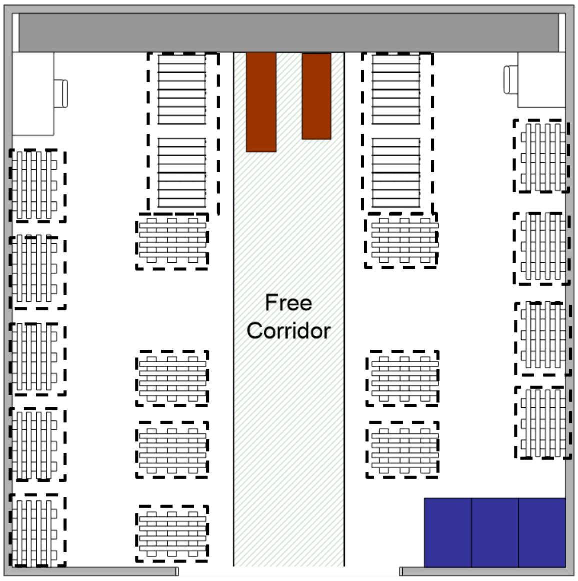

Figure 30. Layout 1

LAYOUT 1. The idea behind this layout is to create a "free corridor" in the middle of the workshop, so workers can enter and exit with pallets or trolleys whenever they want without obstacles in between. Each worker has assigned a side of the room, divided by the "free corridor" – monoplane systems should be placed on the right side of the room because it can "store" fewer pallets than the left side, where biplane systems should go. The desks are located next to the stand in order to support ongoing activities, such as placing smaller parts from the material trolleys there for inspection or for destroying labels. There are predefined places to leave the pallets and the material trolleys marked with lines on the floor, helping standardize the process. This is a tool of visual management and it will help workers perform their job, boosting performance and therefore productivity, as well as decreasing human error and motion wastes.

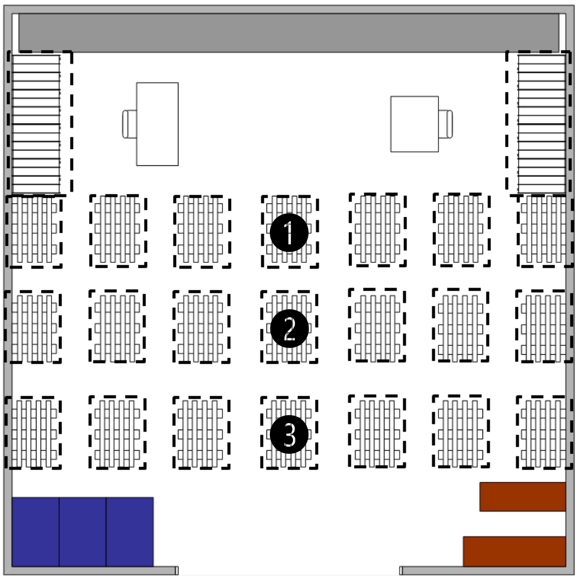

Figure 31. Layout 2

LAYOUT 2. Similar to layout 1, the desks and the material trolleys are placed near the stand in order to support the ongoing activity. Each worker has its own side of the room. The pallets and material trolleys have predefined areas to be left on, inside marked lines on the floor, as a method of standardization and as a visual management tool. The pallets are distributed through 3 rows: as there is no specific order to bring or take the pallets to/from the room, then the workers should simply place the pallets firstly in row 1, then in row 2 and finally in row 3; to take them out, it is necessary to first remove the pallets in row 3, then in row 2 and lastly in row 1. With this layout, it is expected to reduce or eliminate wastes of motion and increase worker productivity.

The **5S** methodology was chosen based on the work by Pawlik, Ijomah, & Corney (2013) and Kurilova-Palisaitiene (2018). It focuses on organizing the workshop in order to get the most out of it. On his famous book, Hirano (1995) describes 5S as the 5 pillars of the visual workplace: “seiri” (organization), “seiton” (orderliness), “seiso” (cleanliness), “seiketsu” (standardized clean-up), and “shitsuke” (discipline). Organization has to do with identifying what is needed and should be kept and what is unneeded and should be eliminated, orderliness with keeping needed items in the correct place to allow for easy and immediate retrieval, cleanliness with keeping the workshop swept, cleaned and in order, standardized clean-up is what is achieved by maintaining the previous three S’s, and discipline means always following specified and standardized procedures (Hirano, 1995). In this practical case, organization was achieved by removing machine A as it was unneeded for the process, and by identifying all the necessary tools to perform the job; the remaining ones were also removed from the workshop. Then, it was necessary to store the tools in a proper place, starting the orderliness process. A toolbox trolley was decided to be the best option for the SPH process, because they constantly need to move around the workshop to inspect the several pallets, and like this they can easily take the trolley with them, having the tools readily available for use. After closing a system, it was observed how the workers performed the cleaning of the workshop, which fundamentally concerned with sweeping the floor. Although this is a good practice, it is necessary to bear in mind that they are dealing with medical systems, and therefore can carry pathological agents. They were advised to properly disinfect the workshop after each system, also mopping the floor and cleaning any surface with disinfectant, and of course sanitize hands (even though they wear gloves during the whole process). By doing these three things, a standardized clean-up is achieved and is currently established as a Standard Operating Procedure. More than a methodology, 5S is a philosophy and therefore it must be taught and its message reinforced so that workers can internalize it and naturally incorporate it into their daily routine. In this case, lean practice supervision and mentorship was fundamental to achieve the "discipline" pillar.

Visual Control contributes to a visual workplace and is employed to communicate information or instructions via visual signs, without interrupting the process/operation. In this case, visual control consisted of floor line marking and signage to help workers place the pallets in a way that optimizes space usage and motion.

Implementing the previous two methodologies contributes to achieve a **continuous flow**, by reducing interruptions in the process whether to move obstacles out of the way or to search for tools left scattered or even missing. Moreover, **standardization** is also achieved. The notions of the 5 lean principles were also targeted, especially principles 1, 2 and 3: identify the value and the value stream, eliminate waste, and create flow.

Analysing the two layouts, advantages and disadvantages can be identified and are presented in **Table 22**.

Table 22. Layout 1: Pros and cons

	Pros	Cons
LAYOUT 1	• The free corridor optimizes the workflow and workers motion, as they have more space to circulate and perform their job. • The predefined marks on the floor help the workers performing their job by creating a standard procedure and consequently increasing their productivity (= layout 2). • The stand is used to assist the ongoing activities. Moreover, it will help maintain a cleaner and more organized workshop by providing storage space (= layout 2).	• The left side of the room can store more pallets than the right side of the room. This means that when there is one biplane system to harvest, it needs to be planned ahead that the left side of the room is available for when this system arrives, otherwise it will put this system on hold until the space is available, increasing work in progress. • As this layout can "store" less pallets than layout 2 (16 < 21), it might happen that one entire system can't be placed inside at a single time, leaving pallets outside. However, with the creation of the free corridor, it shouldn't be a big concern to having to take out pallets as soon as they are ready and bring the remaining inside.
LAYOUT 2	• There is an increased space utilization when compared to layout 1 (21 vs. 16 pallets storage), which means that by looking to **Table 21**, it is most likely to happen that all pallets belonging to the two incoming systems for harvesting at the same time (whether 1x biplane + 1x monoplane or 2x biplane – the most challenging situations in storage matter) can be placed inside simultaneously, reducing even further wastes of motion. • The predefined marks on the floor help the workers performing their job by creating a standard procedure and consequently increasing their productivity (= layout 1). • The stand is used to assist the ongoing activities. Moreover, it will help maintain a cleaner and more organized workshop by providing storage space (= layout 1).	• For one side, waste of motion might be reduced by having all at the same time the pallets placed inside, but on the other side bringing in and taking out the pallets it is not so intuitive and requires the workers to place them in a specific order. By analysing the workflow of both layouts in Appendix C and Appendix D, it can be drawn the conclusion that the workflow seems to be smoother and more easily executable in layout 1 rather than in layout 2.

4.3.2.3. Final selection

Having the layouts developed, these were later presented to Siemens Healthineers and Simon Hegele and voted by both parties, and layout 1 was preferred. The implementation of layout 1 was supervised and the Spare Parts Harvesting workers trained to adapt to the new workflow. The new layout was fully implemented by the time at which the practical test with the new lists was carried out. The new workshop layout is show from **Figure 32** to **Figure 38**:

- In **Figure 32**, the overview of the new SPH workshop can be seen, with the free corridor in the middle of the area, also separating the right and left side assigned to each SPH worker.
- **Figure 33** and **Figure 34** detail each side of the workshop and it can be perceived that the pallets were purposefully placed in an orderly manner.
- **Figure 35** and **Figure 36** highlight the available space to move around the pallets, improving work performance.
- **Figure 37** refers to the area where the machine A used to be, and where is now a workplace. It can also be seen a material trolley placed near the stand, so workers need only one step to place the small parts on the counter.
- **Figure 38** shows the toolbox trolley where tools are stored and also another material trolley placed near the stand: it can actually be seen some small parts awaiting label destruction on the counter (highlighted in orange).

Figure 32. Overview of the SPH workshop after improvement

Figure 33. Left side assigned to biplane systems

Figure 34. Right side assigned to monoplane systems

Figure 35. Pallets positioning inside the workshop (1)

Figure 36. Pallets positioning inside the workshop (2)

Figure 37. Area where machine A was stored

Figure 38. Toolbox trolley, material trolley near the stand and small parts highlighted in orange on top of the counter

This concludes the improvement of the Spare Parts Harvesting process resorting to lean methodologies, tools and practices. The process is now fully structured and standardized, and the impacts on the process will be discussed in the following section 4.4.. Nevertheless, one of the five lean principles is the pursuit for perfection, which means that even after a process has been improved, it must be continuously supervised to identify new improvement opportunities. The PDCA cycle is a lean tool for continuous improvement (Vasanthakumar, Vinodh, & Vishal (2017), Pawlik, Ijomah, & Corney (2013), Kurilova-Palisaitiene (2018)) and comprises four phases: 1) Plan, 2) Do, 3) Check, and 4) Act. Upon identifying an improvement opportunity, it is necessary to elaborate a plan to achieve it, the action plan. After the plan is outlined it is time to put it into practice, which marks the "Do" phase. To assess whether the implementation of the plan was successful or not, it is necessary to "Check" the process and if the desired outcome was achieved: if yes, standardize the process and share lessons learned; if not, reflect on what went wrong and can be improved and restart the PDCA cycle. The SPH process will be continuously monitored resorting to the PDCA cycle in order to comply with the fifth lean principle.

4.4. Achieved results and follow up

The present section aims at assessing the impact of the implementation of lean in the Spare Parts Harvesting process and conclude whether or not an improvement was achieved. To do so, two tasks were carried out: 1) a questionnaire was delivered to the SPH workers to understand how they feel with the new process and how they evaluate the changes that took place, and 2) the process was observed over the course of two weeks to identify if the desired outcome was achieved. These two tasks constitute the data collection step illustrated in the previous **Figure 25**.

The results of the observation process are analysed first:

The search for the needed parts is much faster. It was observed that SPH workers search for the parts much more easily and faster, due to a shorter spare parts list (now spare parts catalogue and that also identifies where the part they are searching for can be found) and more adequate requirements lists, which identifies straight away the parts they need to retrieve, ignoring all the remaining ones.

The disassembly process is much more efficient. This is also a consequence of the new lists, because as the requirements list identifies only the parts needed for stock, the SPH workers need only to check on the spare parts catalogue where those parts can be found and disassemble them. No extra time is wasted by having to disassemble all parts identified as RS HP, to later receive a confirmation whether or not it was necessary to take them out.

New spare parts are being harvested. Regarding the input of spare parts in the 2081 warehouse (the spare parts warehouse), it was already seen that on the day of the practical test with the lists two new parts that were never harvested before were identified as spare parts. Two weeks into the new process, the number of new parts being harvested was of 5. Four months later a new confirmation was requested, and this time a total of 17 new parts entered the 2081 warehouse, generating new 5-digit revenues.

Usually harvested parts are now scrapped. Upon the new confirmation request, it was also verified that around 8 to 10 part-numbers that used to be identified as spare parts are now scrapped, avoiding unnecessary storage and obsolescence costs.

Improved communication between Siemens Healthineers and Simon Hegele. With the introduction of the new lists, the exchanging of one e-mail back and forth was eliminated, making the communication process much more efficient. Currently, Siemens Healthineers matches the requirements list with the cross-check list which automatically identifies those parts that are currently needed for CS and sends the lists only once to the SPH workers. With this new procedure, the SPH workers do not need to send back the disassembly list fully filled, only to receive it again confirming which of those disassembled parts are needed for stock. This non-value-added activity is eliminated and communication between the two parties greatly improved, since the "one" e-mail identifies immediately which parts need to be disassembled and sent to the 2081 warehouse (no extra confirmation is necessary).

Substantial reduction of motion and space wastes. This result was achieved almost immediately, after explaining the logic behind the new layout and training the SPH workers to efficiently bring in and take out the pallets and material trolleys. They can also work and move around the pallets much more easily. Moreover, the area where machine A used to be is now a working place and frees up useful space for the process.

Smooth and continuous workflow. It was observed that the workers do not waste any more time having to move obstacles out of the way and therefore the process suffers no interruptions, contributing to a smooth and continuous workflow.

Substantial reduction in process lead-time. The major outcome of the process improvement was its lead-time reduction, which was the main goal to achieve, and is a consequence of all the previous results. Before process improvement, the lead-time to completely harvest a biplane system was around 12 hours, and a monoplane system around 8 hours. After process improvement, the SPH workers took around 8 hours to harvest a biplane system and 4 hours for a monoplane system, which translates in the substantial lead-time decrease of 33% and 50%, respectively (see **Figure 39**). This will have a major impact in Customer Service department, especially in terms of spare parts inventory management.

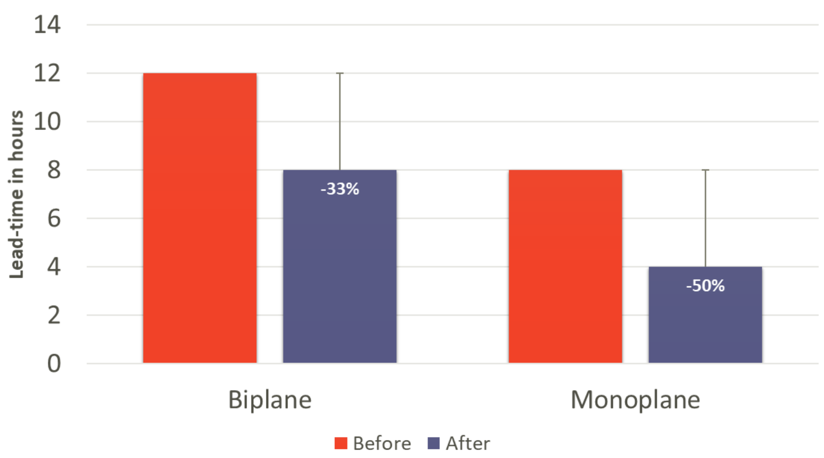

Figure 39. Impact of process optimization on the SPH lead-time

Standardized process. After two weeks of observing the process, it was verified that the SPH workers proceed the exact same way system after system, situation that was not observed before (they did things the way they wanted). Additionally, they were asked to explain the process to different workers and everyone understood how the process had to be carried out. With a standardized process, Siemens can now establish fixed costs per system, which was one of the main goals to achieve with this process optimization.

The results of the questionnaire, which can be consulted in Appendix E, are now analysed. The questionnaire was divided in two parts: part 1 was specified for the old process and part 2 to the new process, to allow a comparison between them. After processing the answers, some contradictions to the previous observations were perceived:

- Regarding the spare parts list, one worker recognizes it was too extensive and confusing and the other says he liked to work with it because he was used to it. In fact, one of the workers even added that regardless of the extension of the list, he was still able to find the parts quickly using excel search box.
- As for the old procedure, there is a division of opinions: one worker says he could easily explain the old process to another person and that person would be able to understand it and perform the job without much trouble, the other says it would be hard to explain and that the new person would face difficulties performing the job.
- Both workers acknowledged that the previous long lead-time to harvest a system could be explained due to writing down all serial and revision numbers for all parts and disassembling all parts identified as RS HP. However, they did not recognize that there was an inefficient communication between Siemens Healthineers – Simon Hegele, nor wastes of motion and poor workshop organization, nor lack of standard procedures.
- It was asked if they could score how satisfied they felt in the old process from 1 to 6, and both gave a score of 4.

Regarding the new process, the results are very curious:

- They state they take the same time as before to find the parts they need to harvest, as well to disassemble them.
- The communication between Siemens Healthineers – Simon Hegele did not improve (this might be explained by the fact that they did not recognize an inefficient communication in the first place).
- One worker adds that the three lists are unnecessary, and in fact all he needs is the disassembly list.
- Regarding the workshop layout, one of the workers recognized he could put small improvements into practice immediately, the other said the work process remained the same.
- One of the workers acknowledged that it is easier to bring in and take out the pallets, and the other doesn't see an improvement.
- For one worker the layout improved the disassembly of parts, for the other it didn't.
- Both gave a score of 5 out of 6 in how satisfied they feel in the new process.

As it can be verified the results are very different from those observed. Nevertheless, the workers said they received proper and sufficient training to adapt to the new lists and the new layout. In the light of these responses, some conclusions were withdrawn. The first and most significant is that there is a resistance to change. The workers were used to the old process and therefore don't understand the need to change (affirmations like "*the list was extensive but I could still find the parts quickly*", "*there is no need for three lists*", etc., support this point). Furthermore, in order to achieve standardization, they must follow certain procedures (or rules) which previously did not exist and thus performed their job as they wanted ("freely"). There might be a feeling of control or supervision that they are not used to and therefore have difficulty to accept. Still, there was a slight increase in worker satisfaction (from 4 to 5 out of 6).

4.5. Chapter conclusions

This chapter introduced the methodological approach followed for the improvement of the Spare Parts Harvesting process. This is a 3-step methodology based on reviewed literature Kurilova-Palisaitiene (2018). The first step had to do with preparation and concerned with gathering information on the process, whether through manager and personnel interviews, observation of shop floor operations, brainstorming meetings or by reviewing the existent literature on lean remanufacturing.

The second step referred to execution, which was divided into 4 points. In the first point of the execution step, three process maps were developed: one to identify all material flows in the Simon Hegele Refurbishing Centre, originating the respective spaghetti diagram and consequently the second process map, and another to identify all information flows in the Spare Parts Harvesting process. These maps were essential to locate inefficiencies in the process, which are mainly due to inefficient information flows. In the second point of the execution step, having the challenges highlighted, a root-cause analysis was performed resorting to an Ishikawa diagram in order to reach to the bottom of each challenge (what is causing them). Five main categories of challenges were identified: challenges in the method (it has mostly to do with the lists used in the process), in the machine (that is, regarding the complexity of the systems received for harvesting), in the material (related to the organization of the tools used to perform the job), in the manpower (refers to the way the process is affected by the people involved in it), and in the environment (that is, the workshop layout and overall organization). The third point of the execution step summarizes the identified challenges and presents improvement opportunities. The fourth and final point of the execution step concerned with developing lean based solutions to tackle those challenges. At the work procedure level, non-value-added activities were eliminated (according to the second lean principle, elimination of waste), and procedures that capture best practice established (Standard Operating Procedures, SOP). At the workshop layout level, 5S methodology, visual management tools (specifically visual control), and layout for continuous flow were implemented. Supervision and mentorship were employed during the whole process improvement to teach and help the SPH workers in the transition to the new process. The process was set out to be continuously monitored in order to comply with the fifth lean principle, pursuit perfection, resorting to lean methodology PDCA cycle.

The third step was the results confirmation step, where the new process was observed and analysed, and the results from process improvement obtained. The biggest impact was on the process lead-time, which saw a 30% reduction for biplane systems and 50% reduction for monoplane systems. Moreover, the process is now fully standardized, with SOP establishing guidelines on what and how to do in each operation. By increasing the number of correctly harvested parts, it is also expected that inventory levels and associated costs (warehousing, stockout and obsolescence costs) decrease. The communication between Siemens Healthineers and Simon Hegele is now more efficient and with less exchange of unnecessary e-mails, sending the correct and needed information only once (at the beginning of the process, for each new system). It was verified that workflow is also smoother due to an improved workshop layout, where motion and space wastes were greatly reduced. The searching and disassembly of parts is performed faster and more efficiently.

5. Final conclusions and future work

The present dissertation was developed in Siemens Healthineers, the healthcare sector of Siemens, and addresses the refurbishing process of end-of-life Advanced Therapies (AT) systems. The drivers behind the implementation of this product recovery solution were not only to meet ambitious sustainable goals set by Siemens but also to elevate the standards for the market of second-hand medical equipment, assuring their quality and safety for use by patients and operators. The refurbishing process contributes to a circular economy and sustainable development by preventing medical systems from becoming waste and instead being reused, saving scarce resources and energy otherwise needed to manufacture new systems with similar attributes, also minimizing greenhouse gas (GHG) emissions. Furthermore, as refurbished systems are more affordable than new medical devices, refurbishing also contributes to increase healthcare access, quality and safety of service provided, as it promotes the replacement of obsolete equipment in hospitals and healthcare providers. It can thus be concluded that improving the refurbishing process is in the scope of the 17 goals for sustainable development established by the United Nations (UN), particularly goal 3 (good health and well-being), goal 10 (reduced inequalities), goal 12 (responsible consumption and production) and goal 13 (climate action) (United Nations, n.d.).

The refurbishing process is done via a "5-step Quality Process", in accordance with the NEMA/MITA standard for refurbishment. They are: 1) Selection, 2) De-installation, 3) Refurbishment, 4) Installation and 5) Services. The Refurbishment step encompasses six other operations: Incoming Inspection, where the system is carefully inspected upon arrival and decided whether it is good enough for refurbishment or else if it should go to recycling; Spare Parts Harvesting, where parts identified by Customer Service (CS) are retrieved from used systems to support warranty services or to be sold in the aftermarket; Cleaning and Disinfection, where the several parts constituting a system good enough for refurbishing are given a "like-new" look; Equipment Reprocessing, where those same parts are sent to the OEM for a technical check-up, repair and update; Reassembly and Final Testing, where the several refurbished parts coming from the OEM are reassembled together and extensively tested to assure its safety and quality; and Packaging refers to the preparation for shipping of the finalized ecoline system. The present case-study focused on the Spare Parts Harvesting (SPH) process.

By reviewing the literature, the main reasons that lead companies engaging in remanufacturing were understood, and contrary to what is usually pointed out (ethical and moral responsibility, product take-back and recovery legislations, and profitability of remanufacturing), it was discovered that securing spare parts supply and warranty, protecting market share and brand image, and enhancing customer orientation are predominant motivators (Seitz, 2007). The economic relevance of a spare parts business was also perceived, with companies with a more professional spare parts logistics presenting an average of 20.5% spare parts revenues over the total revenues (Wagner, Jönke, & Eisingerich, 2012). This constitutes a good argument to further invest and develop a company's spare parts logistics. The main challenge associated with spare parts inventory management is their unpredictable demand behaviour, making it difficult to balance inventory levels in order to avoid both obsolescence and stockout costs (Dekker, Pinçe, Zuidwijk, & Jalil, 2013). Then, the lean tools, methodologies and practices implemented in the context of remanufacturing were investigated. Process mapping and root-cause analysis methodologies were found useful to identify challenges in the process (Ishikawa (1976), Liker (2004), Andersen & Fagerhaug (2006), Pawlik, Ijomah, & Corney (2013), Kurilova-Palisaitiene & Sundin (2014)). The five lean principles were identified as guidelines to improve processes, and considering the nature of the problem addressed in this dissertation, the first (identify the value and the value stream), second (eliminate waste), third (create flow) and fifth (strive for perfection) principles are particularly targeted, based on Dayi, Afsharzadeh, & Mascle (2016). Layout for continuous flow was identified as a specific tool to improve workflow and eliminate wastes in the workshop (Östlin & Ekholm (2007), Kanikuła & Koch (2009), Kurilova-Palisaitiene (2018)). Standard Operating Procedures (SOP), 5S, and visual management tools like visual control are used to achieve improvements in quality management (Kurilova-Palisaitiene (2018), Pawlik, Ijomah, & Corney (2013)). A gap in the literature was found regarding the clear distinction between refurbishing and remanufacturing concepts, as well regarding the implementation of lean in spare parts harvesting processes, and for which this dissertation provides an academic contribution.

The improvement of the process followed a 3-step methodology, where first the relevant information about the process was collected (preparation step). Then, the effective identification of challenges and improvement opportunities in the process resorting to process mapping and root-cause analysis (RCA) tools was accomplished. Process maps were developed to study the material flows in the Simon Hegele Refurbishing Centre (originating the respective spaghetti diagram) and in the Spare Parts Harvesting process, as well to identify inefficiencies in information flows. RCA was developed resorting to an Ishikawa diagram and the main challenges were grouped into 5 categories: method, machine, material, manpower and environment. To this followed the development and implementation of other lean tools, methodologies and practices reviewed in the literature and identified in the previous paragraph so as to improve and overcome the identified challenges (execution step). Finally, the new process was observed and analysed, allowing to obtain the results from the process improvement (results confirmation step). The main results obtained from this implementation were the following: a faster and more efficient search and disassembly of needed parts; spare parts that were never harvested before are now retrieved and the contrary is also true, that is, parts that used to be harvested but are not needed are now scrapped, increasing the number of correctly harvested parts; communication between Siemens Healthineers and Simon Hegele improved, with a more efficient exchange of information; wastes of motion and space were significantly reduced, resulting in a smooth and continuous workflow; process lead-time decreased by 30% for biplane systems and 50% for monoplane systems; and overall process standardization was achieved. The Spare Parts Harvesting process improvement contributes to improving circular economy by recovering parts that can be reused, therefore reducing the consumption of resources and production activities needed to produce that same part, also minimizing the carbon footprint. Additionally, it positively impacts the economic performance of the company by improving spare parts inventory levels and reducing related warehousing, stockout and obsolescence costs, as well improving spare parts revenues by keeping correct inventory that can be sold in the aftermarket. Considering the society pillar, the Spare Parts Harvesting process contributes to more affordable repairs and medical systems, stimulating preventive and regular maintenances which in turn avoid obsolescence of installed equipment, and motivating hospitals and healthcare providers with budgeting constraints to replace their old equipment by acquiring refurbished systems with discount (in case the old equipment is returned), therefore also increasing healthcare access and preventing medical systems from becoming waste.

However, as one of the main lean principles is striving for perfection, the process must be continuously monitored to identify new challenges and improvement opportunities. The continuous improvement tool PDCA cycle was therefore also established as best practice.

As mentioned, the Spare Parts Harvesting process, which was the focus of the present work, is carried out at the Simon Hegele Refurbishing Centre (inside Siemens Healthineers Forchheim campus), along with the Incoming Inspection and Cleaning and Disinfection. Since the Spare Parts Harvesting process is directly related with the Incoming Inspection, and therefore affected by it, improving this process performance directly impacts the performance of the Spare Parts Harvesting process. Based on literature review and from observing the overall process, some further improvement suggestions can already be made.

In the Incoming Inspection, parts are sorted based on their condition: if the parts are in fairly good condition and are needed for ecoline systems, they proceed to the Cleaning and Disinfection process, otherwise all parts are sent to the Spare Parts Harvesting Process. In the disassembly step of the 5-Step Quality process, it was seen that medical systems are shipped from the customer to Forchheim separated in its several main parts. So, it can happen that one main part of a system has spare parts inside and other main part of the same system has not. Currently, in the Incoming Inspection it is not checked whether a main part actually has spare parts inside or not, it is always sent to the SPH. However, with the new spare parts catalogue this check-up could be easily made and avoid an unnecessary part entering the SPH process, consuming time, space and resources. With an extra “filter” in the Incoming Inspection, in addition to sorting parts based on their condition, they would also be sorted by whether or not they contain spare parts, further improving both processes. This suggestion was thought taking into account the lean methodology SMED (Single Minute Exchange of Die), famous for its impact in reducing setup times (Kurilova-Palisaitiene, 2018). For clarity, see **Figure 40** (for comparison with the current parts assortment, check **Figure 11**).

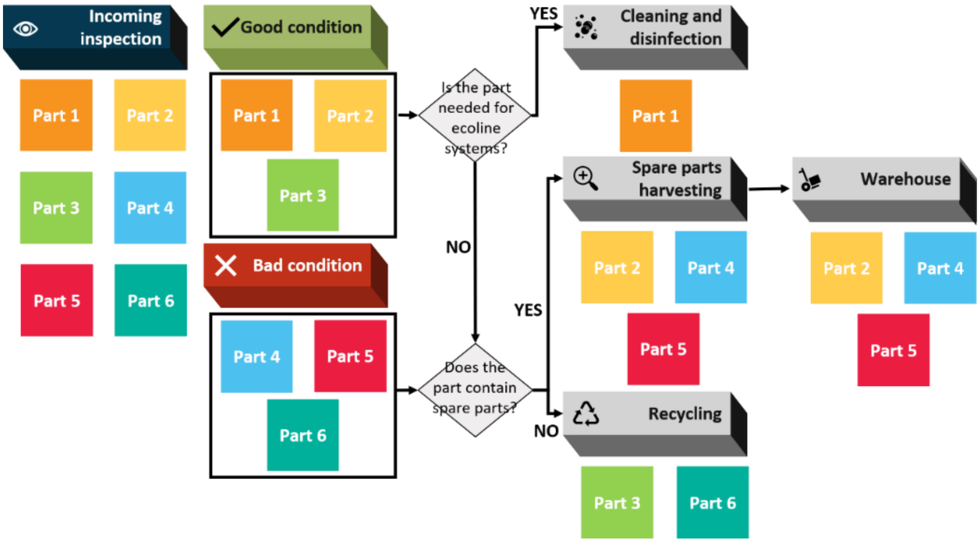

Figure 40. Suggested parts assortment (Incoming Inspection) for future implementation

Another suggestion is regarding the further improvement of the spare parts catalogue. This was already a big step forward regarding the old spare parts list but nevertheless, and taking into account the teachings of continuous improvement, it could be upgraded if there was a virtual catalogue, resorting for instance to 3D modelling (like CAD software), in which it would be possible to visualize the system and all its parts, components, etc. (its BOM, bill of material). So, for example, when searching for a specific part-number, that part would be highlight in the 3D model and the worker could visualize where exactly is located inside the system, making the process even more agile. Since lean implementation was a success for the Spare Parts Harvesting process of Advanced Therapies (AT) systems, then the lessons learned can be extracted for the same process of the remaining business lines (MR, MI and CT).

It was also seen during literature review that for future work it would also be interesting to explore the concept of supply chain design in order to determine the optimal warehousing and refurbishing centre locations, so as to optimize the lead-time delivery of parts to customers and further tackle the lead-time challenge when dealing with spare parts inventory management. Furthermore, currently there is no information sharing nor inventory pooling among the three spare parts warehouses around the globe, wasting synergies and an opportunity to improve customer service, but also increasing the risk of incurring in stockout or obsolescence costs. Therefore, it would also be interesting to analyse the implementation of a centralized information system between spare parts warehouses. Furthermore, another research opportunity was identified regarding the improvement of the spare parts inventory management and which concerns with developing a forecasting model based on the wear behaviour and technical condition of systems, predicting the failure and deterioration of specific parts, enabling to adjust inventory levels to the predicted spare parts demand. The reasons for Siemens Healthineers engaging in the refurbishing of medical systems defined in **Table 11** also lack validation.

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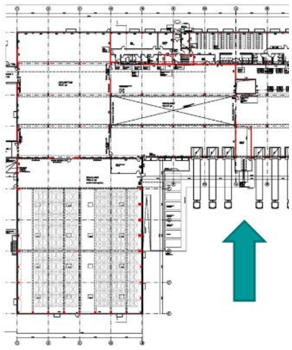
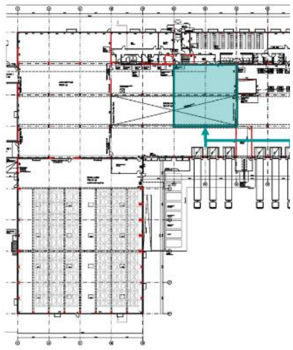
Appendices

Appendix A. Material flow in the Simon Hegele refurbishing centre



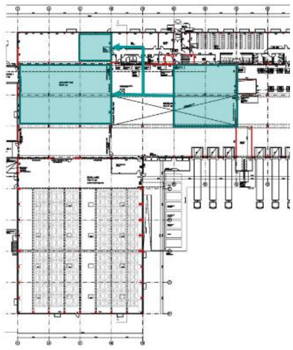
1

Systems arrive at the unloading dock.



2

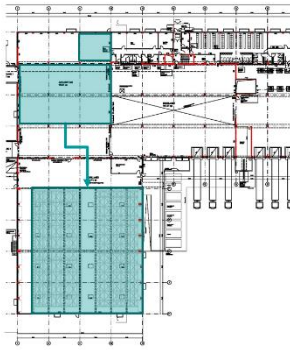
Systems are taken to the “Incoming Inspection” area.



2.1.

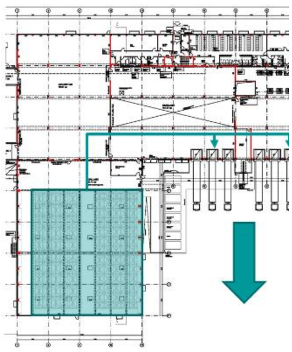
If systems are **good** to refurbish:

I. They go to the “Cleaning and Disinfection” area;



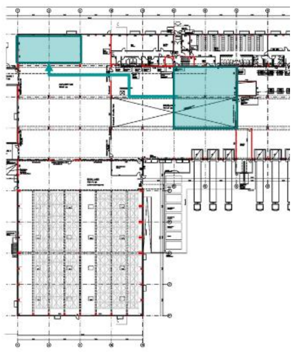
2.1.1.

II. Then are stored in the warehouse;



2.1.2.

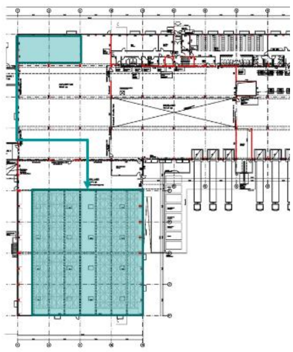
III. And finally are shipped to Kemnath to finish the refurbishment.



2.2.

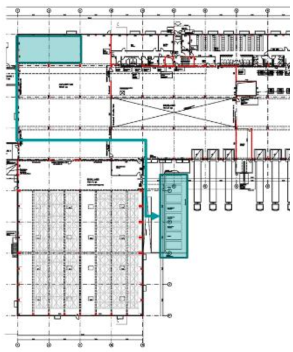
If systems are **not good** to refurbish:

I. They go to the “Spare Parts Harvesting” area;



2.2.1.

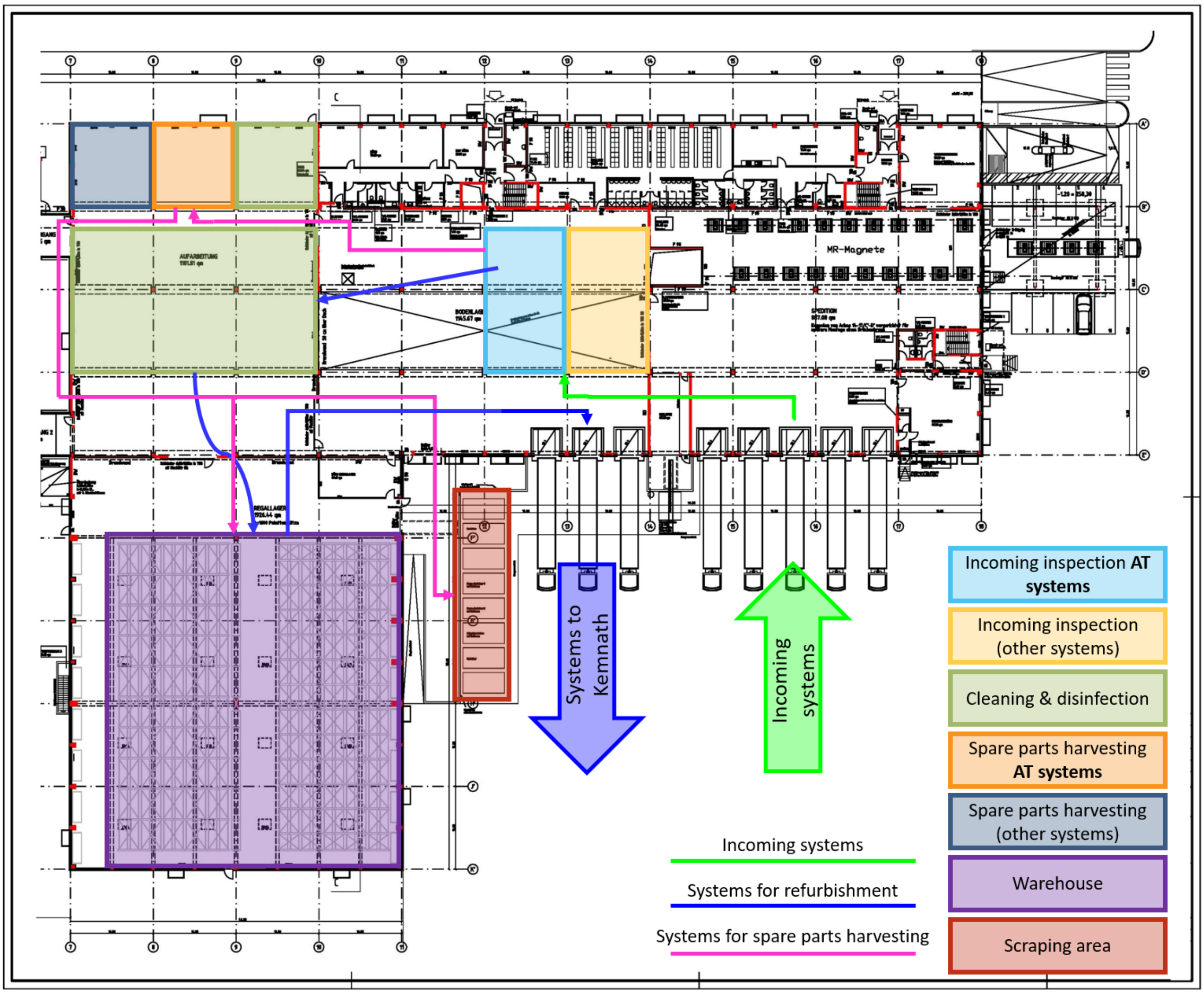
II. The parts needed for stock are taken to the warehouse;



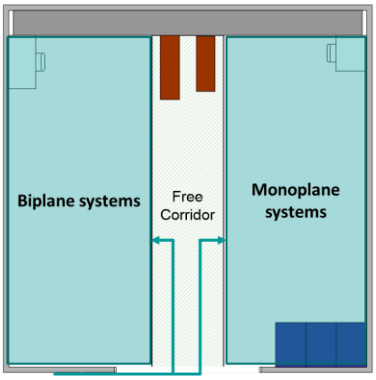
2.2.2.

III. The remaining parts are scraped.

Appendix B. Spaghetti diagram of the Simon Hegele Refurbishing Centre



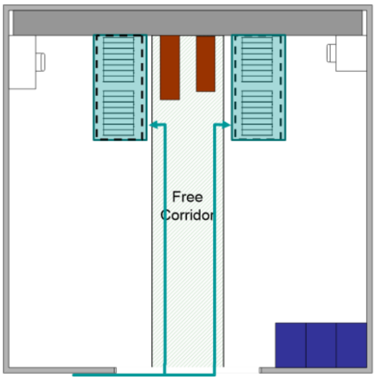
Appendix C. Material flow in the Spare Parts Harvesting area (Layout 1)



1

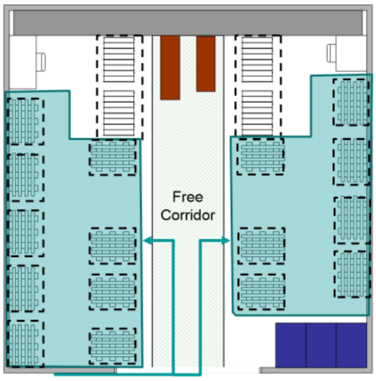
Pallets and material trolleys are waiting outside, in line;

In this layout, the biplane systems are placed on the left side because it can "store" more pallets (until 8/9 pallets) and monoplane systems are placed on the right side.



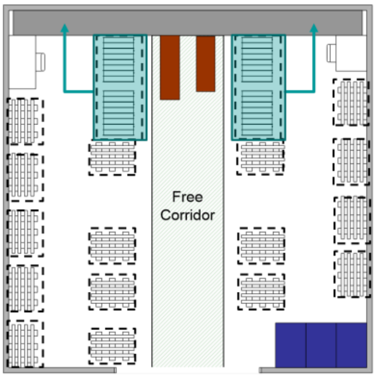
2

The material trolleys should be placed near the stand for better motion efficiency, as well inside marked lines on the floor.



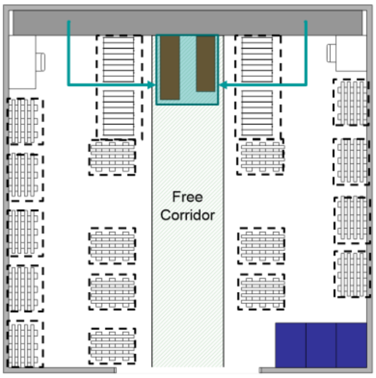
3

Place the pallets inside predefined spaces marked with lines on the floor.



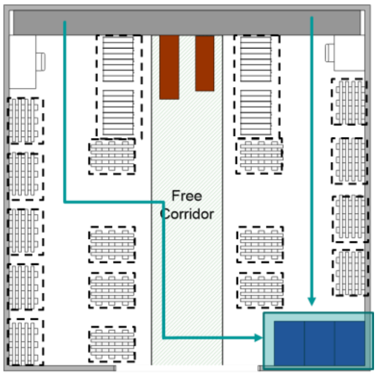
4

Place the smaller parts on the stand for inspection and destruction of labels.



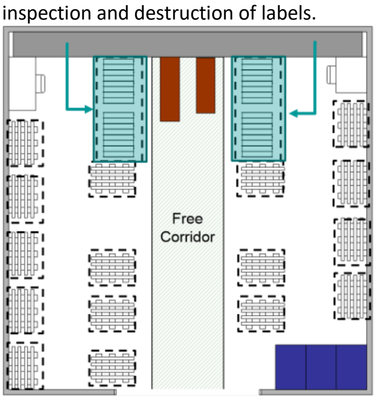
5

The parts needed for stock are placed in a wooden box on top of the pallet-truck.



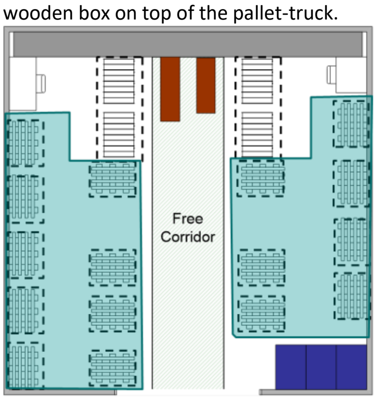
6

The parts that can be recycled are placed in the respective lattice box.



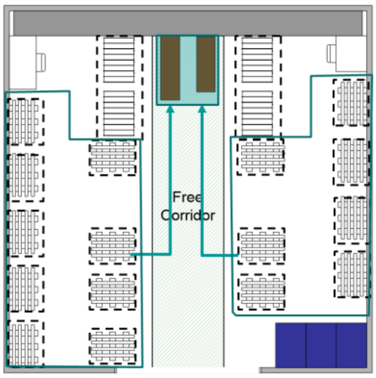
7

The remaining parts are placed in the material trolley again so later they can be taken to the scrapping area.



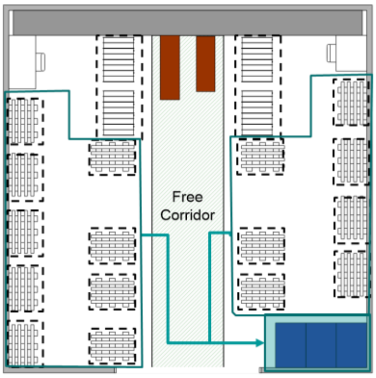
8

The workers inspect the parts in the pallets next to them.



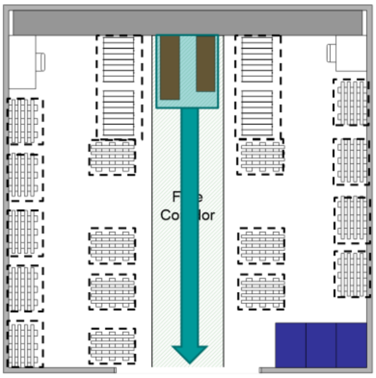
9

The needed parts for stock are disassembled from the bigger parts and stored in the wooden box on top of the pallet-truck.



10

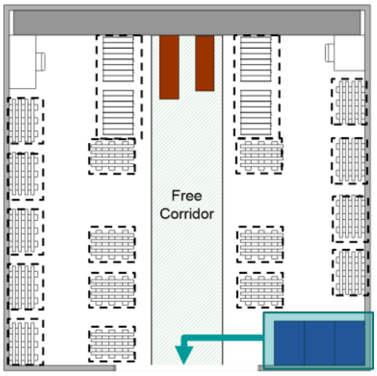
The parts that can be recycled are also disassembled (e.g. motors containing oil, electrical wires, etc.) and placed in the respective lattice box.



11

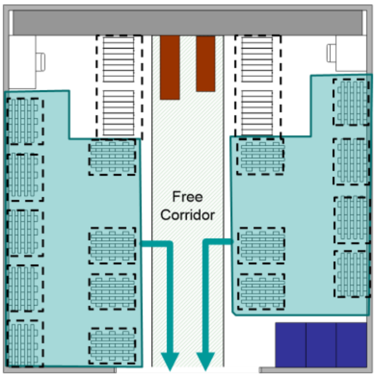
Now that the harvesting of these systems' parts is complete, the workshop must be cleaned:

I. Take the wooden boxes with parts needed for stock to the warehouse;



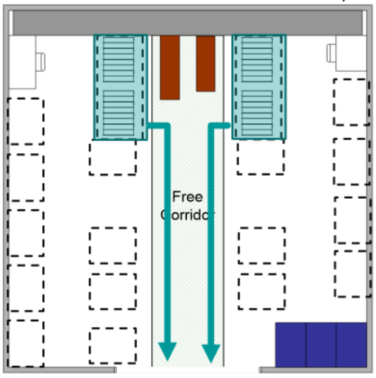
12

II. Take the lattice boxes to the scraping area outside;



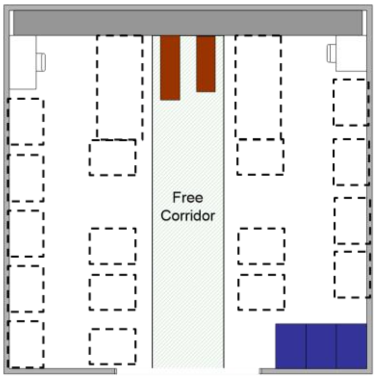
13

III. Take the pallets out;



14

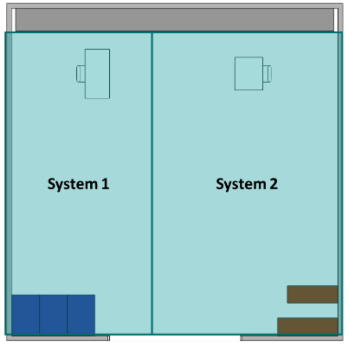
IV. Take the material trolleys out;



15

V. Clean the workshop.

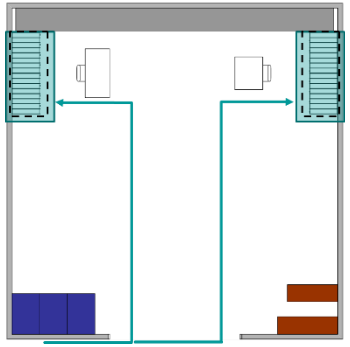
Appendix D. Material flow in the Spare Parts Harvesting area (Layout 2)



1

In this layout, one system is handled on the left side of the room and the other on the right side. In this example, in case there is a biplane system, it is placed on the right side (= system 2).

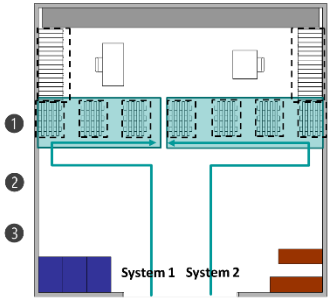
In case there are 2x monoplane systems, both sides can "store" equal number of pallets.



2

Pallets and material trolleys are waiting outside, in line.

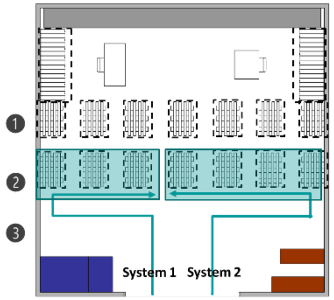
The material trolleys must be placed first, near the stand, inside marked lines on the floor.



3

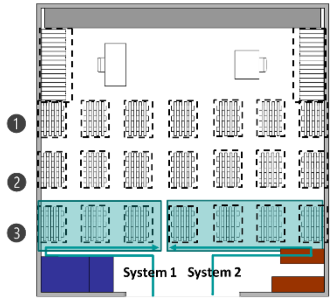
Place the pallets inside in predefined spaces marked with lines on the floor:

I. First, place the pallets in row 1 from the back of the room to the middle;



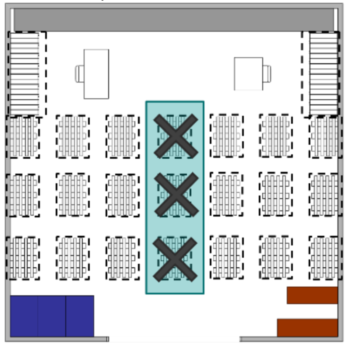
4

II. Second, place the pallets in row 2;



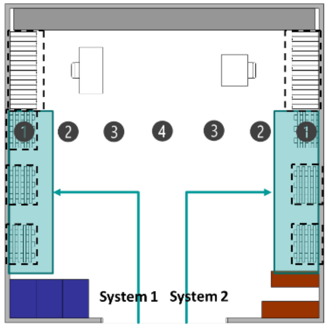
5

III. At last, place the pallets in row 3.



6

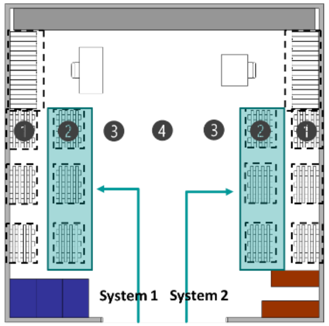
In case of fewer pallets (e.g., if there are 2x monoplane systems instead of 1x monoplane + 1x biplane), leave a "free corridor" in the middle.



7

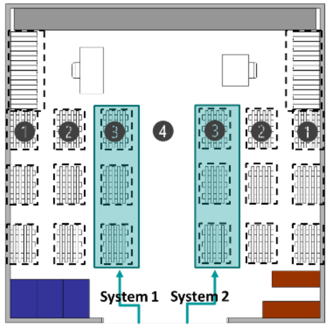
ALTERNATIVE:

I. First, place the pallets in row 1;



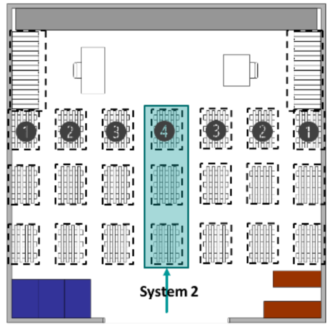
8

II. Second, place the pallets in row 2;



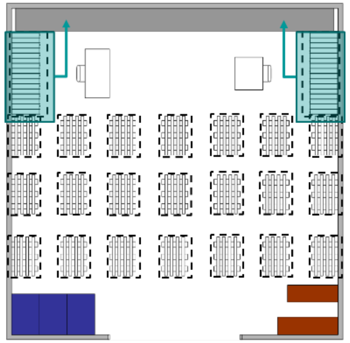
9

III. Finally, place the pallets in row 3;



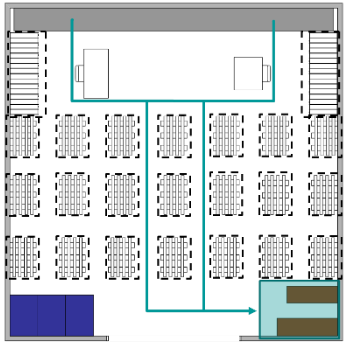
10

IV. If there is a bigger system which has more pallets (e.g., biplane), then place the remaining in row 4.



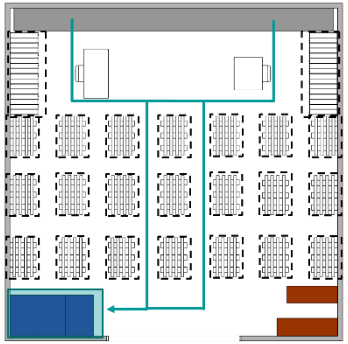
11

Place the smaller parts on the stand for inspection and destruction of labels.



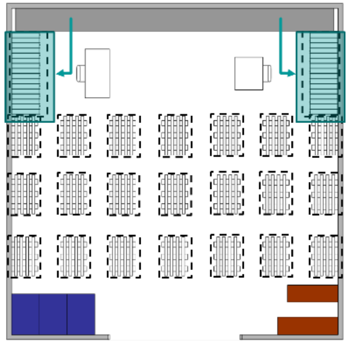
12

The parts needed for stock are placed in a wooden box on top of the pallet-truck.



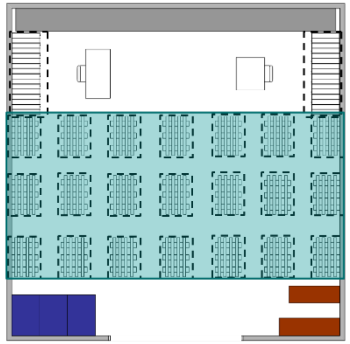
13

The parts that can be recycled are placed in the respective lattice box.



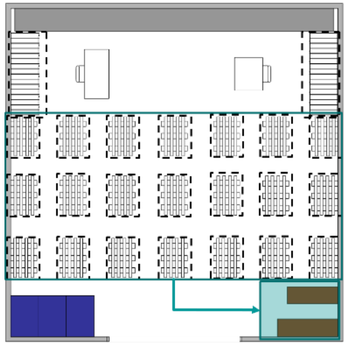
14

The remaining parts are placed in the material trolley again so later they can be taken to the scrapping area.



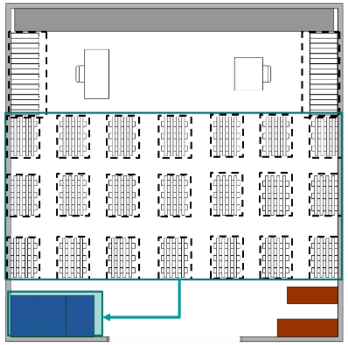
15

The workers inspect the parts in the pallets next to them.



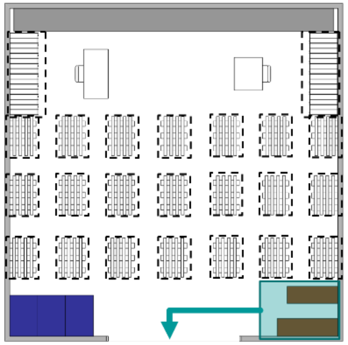
16

The needed parts for stock are disassembled from the bigger parts and stored in the wooden box on top of the pallet-truck.



17

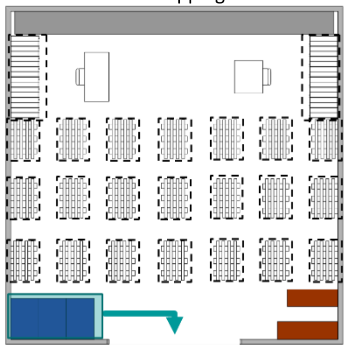
The parts that can be recycled are also disassembled (e.g. motors containing oil, electrical wires, etc.) and placed in the respective lattice box.



18

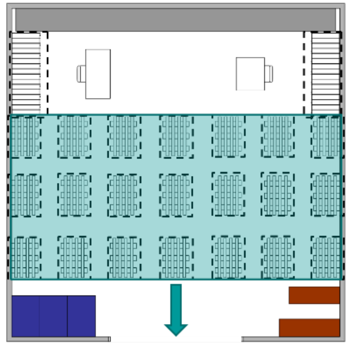
Now that the harvesting of these systems' parts is complete, the workshop must be cleaned:

I. Take the wooden boxes with parts needed for stock to the warehouse;



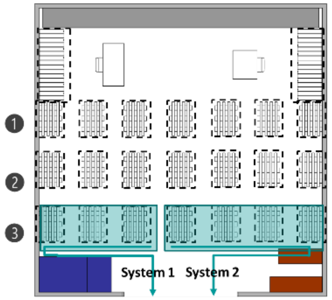
19

II. Take the lattice boxes to the scraping area outside;



20

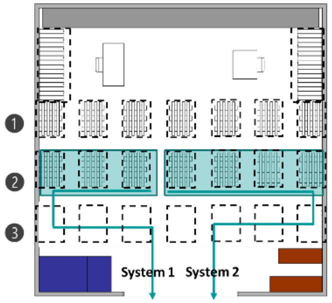
III. Take the pallets out (addressed in the following images);



21

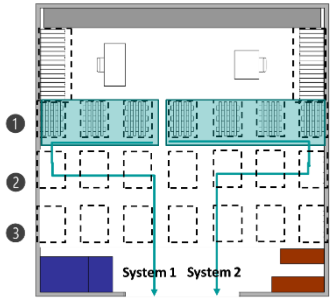
III. To take away the pallets, it is necessary to follow the inverse logic:

i. First, take away the pallets in row 3 from the middle of the room to the back;



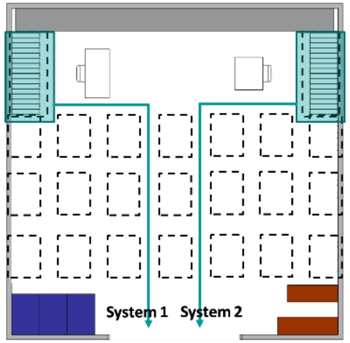
22

ii. Second, take away the pallets in row 2;



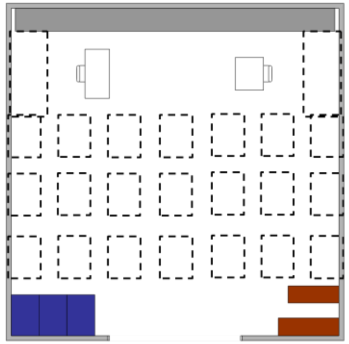
23

iii. At last, take away the pallets in row 1.



24

IV. Take the material trolleys out;



25

V. Clean the workshop.

Appendix E. Questionnaire delivered to the SPH workers to assess the KPIs established to track improvement

Spare Parts Harvesting process – feedback

The present form aims at measuring the impact of the actions/improvements accomplished in the Spare Parts Harvesting process: this includes the process with the new spare parts list & the organization of the workshop. In this form you can expose your honest opinion regarding the changes in the process. Your feedback is very important!

The form is anonymous.

Part 1: "Old" Spare Parts Harvesting process

The following section focuses on the process before any improvement.

Please note that the "old" spare parts list refers to the list with 2,000+ parts and where you used to fulfil the serial and revision numbers, after which you would send to Siemens Healthineers who would then send it back to you showing which parts were to store and which parts were to scrap.

1. How did you feel regarding the "old" spare parts list? You can choose more than 1 option.
   - ☐ It was simple and easy to work with.
   - ☐ I liked to work with the list because I was used to it. 50%
   - ☐ It was too extensive and confusing. 50%
   - ☐ I didn't really understand what I was doing with the list.

2. In the "old" process, you used to fulfil the serial and revision numbers for every part-number you would find in the system, even if on the list it was clearly identified as a part to scrap. Why did you do this?
   - ☐ I was told to do so. 50%
   - ☐ I thought it was better to do so. 50%
   - ☐ I don't know.

3. Imagine that you were on holidays for a week and had to be replaced by someone who never saw the Spare Parts Harvesting process before. Choose the best option:
   - ☐ With the "old" spare parts list, I could easily explain the process to someone else and the new person would be able to understand it and perform the job without much trouble. 50%
   - ☐ With the "old" spare parts list, I would find it hard to explain my job to someone else and I believe the new person would face difficulties performing the job. 50%

4. Regarding the previous answer:

☐ I believe the productivity of the new person would be similar to mine (= it would take the same time as me to completely harvest a system).

☐ I believe the productivity of the new person would be greatly affected (= it would take longer than me to completely harvest a system). 100%

5. How long, more or less, did you take in the "old" process to completely harvest a MONOPLANE system (in hours)?

10h (50%)

8h – 10h (50%)

6. How long, more or less, did you take in the "old" process to completely harvest a BIPLANE system (in hours)?

12h – 16h (50%)

12h – 18h (50%)

7. What do you think contributed to the time you previously mentioned? You can choose more than one.

☐ The list was too big and it was hard to find the part-numbers I needed.

☐ I had to write down all the serial and revisions numbers for all the part-numbers in the system (even if they were to scrap). 100%

☐ I had to disassemble all parts that were "RS HP" from the system and wait for confirmation of which of those were actually to store. 100%

☐ The poor/inefficient communication between Siemens Healthineers - Simon Hegele.

☐ The workshop was disorganized, which lead to wastes of motion.

☐ There was no standard procedure in the Spare Parts Harvesting process (I could work one system in one way and another system in another way, there were no guidelines on how to perform the job).

☐ Other:

The old list was pretty extensive, but I still found the material quickly using the search box! 50%

8. How satisfied were you with the old process?

	1	2	3	4	5	6	
Not satisfied at all, I found it hard to do my job.	☐	☐	☐	☒ 100%	☐	☐	Very satisfied, I wouldn't change a thing.

<u>Part 2: "New" Spare Parts Harvesting process</u>

The following section focuses on the process after improvement.

The "new" spare parts list is a set of four lists: 1) requirements list, 2) cross-check list, 3) disassembly list, 4) spare parts catalogue. Please note that you only handle the requirements list and the disassembly list; the cross-check list and the spare parts catalogue are updated every month by Siemens Healthineers and are of consultation only.

1. When the "new" process was first explained to you, what were your thoughts?
   - ☐ I was reluctant: I did not understand how four lists could be better than one.
   - ☐ I was reluctant: I liked the old process and I didn't understand why it was necessary to change it.
   - ☐ I was intrigued: although I was not sure how these lists could improve the process, I wanted to learn. 50%
   - ☐ I was motivated: I could see that the lists would improve the process and make the job easier. 50%
   - ☐ Other: ____________________

2. Describe your experience when you first worked with the lists on a system.
   - ☐ The whole process was confusing, I liked the "old" process better.
   - ☐ The process was confusing at first but after asking questions and clearing my doubts I started to understand it. 100%
   - ☐ The whole process was confusing, even after clearing my doubts I did not understand what I was supposed to do.
   - ☐ I clearly understood the process and had no significant doubts.
   - ☐ Other: ____________________

3. Is it now easier for you to find the parts you need to harvest?
   - ☐ Yes.
   - ☐ No, I take longer.
   - ☐ No, it takes me the same time. 100%
   - ☐ I don't know.

4. Is it now easier for you to disassemble the parts you need to harvest?
   - ☐ Yes.
   - ☐ No, I take longer.
   - ☐ No, it takes me the same time. 100%
   - ☐ I don't know.

5. Is it now easier for you to fulfil the list you must send to Siemens Healthineers (the disassembly list)?
   - ☐ Yes. 100%
   - ☐ No, I take longer.
   - ☐ No, it takes me the same time.

☐ I don't know.

6. Would you say that the communication between Siemens Healthineers - Simon Hegele improved (regarding, for example, the confirmation of the parts to store)?

☐ Yes.

☐ No. 100%

☐ I don't know.

7. Would you say that you received proper and sufficient training to work with the new lists?

☐ Yes. 100%

☐ No.

☐ I don't know.

8. Do you have any other suggestions to improve the spare parts lists? There are no wrong nor bad ideas!

Combine the disassembly list and the spare parts catalogue in one list 50%

Not until now! 50%

9. Shortly after the introduction of the new lists, the workshop was also subject of improvement. How did you feel when you were shown the new planned layout?

☐ When I saw the plan, I didn't particularly liked it: I thought the actual organization was just fine.

☐ When I saw the plan, I had difficulty imagining the workflow and how the workshop would become more organized.

☐ When I saw the plan, I understood the idea behind it but I would suggest some changes.

☐ When I saw the plan, I liked the idea and I could picture it working in practice. 100%

☐ Other: ____

10. When the new planned layout was implemented, how did you feel?

☐ I did not like the new layout, it felt forced.

☐ I had some trouble moving around.

☐ Overall, I enjoyed the new layout, I could move around better although I think it could be further improved.

☐ I realized a greater motion efficiency as I did not need to constantly move pallets out of the way.

☐ Other: The work process remained the same 50%

I like the new layout very much – we put small improvements into practice immediately! 50%

11. Is it now easier for you to bring in and take out the pallets and material trolleys?

☐ Yes. 50%

- ☐ No. 50%
- ☐ I don't know.

12. Is it now easier for you to disassemble the parts you need to harvest?
    - ☐ Yes. 50%
    - ☐ No. 50%
    - ☐ I don't know.

13. Is it now easier for you to clean the workshop after finishing one system?
    - ☐ Yes.
    - ☐ No. 100%
    - ☐ I don't know.

14. Would you say that you received proper and sufficient training for the new workshop organization?
    - ☐ Yes. 100%
    - ☐ No.
    - ☐ I don't know.

15. How was the transition from the "old" to the "new" process for you? This includes the adaptation to the new lists and to the new workshop organization.

	1	2	3	4	5	6	
The transition was very hard, I'm still having a hard time adapting to the new process.	☐	☐	☐	☐	☒ 100%	☐	The transition was very good, I had absolutely no problem adapting to the new process.

16. How satisfied are you with the new process?

	1	2	3	4	5	6	
Not satisifed at all, I preferred the old process.	☐	☐	☐	☐	☒ 100%	☐	Very satisfied, the new process helps me perform my job better.

17. Do you have any other suggestions to improve the workshop organization? There are no wrong nor bad ideas!

    All that is needed for the process is the disassembly list; the additional lists are unnecessary. 50%

    Not at the moment! 50%

Thank you very much for your time!

Your answers will be processed.