

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

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**Abstract.** Lean has been extensively used to improve processes within the manufacturing industry, with great impact on lead-time reduction, elimination of wastes and non-value-added activities and standardization. With product take-back obligations and increasing awareness towards the environment, manufacturers were held responsible for the whole life cycle of their products, and several product recovery options began to appear, including remanufacturing, refurbishing, repair, and recycling. Due to the high uncertainty the remanufacturing industry is subject to (namely in regard with quality, quantity and timing of returned products), lean has been increasingly implemented in this context to tackle remanufacturing challenges. This paper addresses the Spare Parts Harvesting process of medical systems, which is part of a refurbishing process, and aims at investigating the impact of lean implementation to improve identified challenges in the process.

**Keywords:** lean, product recovery management, refurbishing, second-hand medical systems, spare parts harvesting, process optimization, remanufacturing challenges.

## 1. Introduction

The present paper was developed within the healthcare industry and addresses the refurbishing process of end-of-life medical systems. The drivers behind the implementation of this product recovery solution were not only to meet ambitious sustainable goals 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 [1].

Refurbishing contributes to a circular economy and sustainable development by preventing medical systems from becoming waste and instead being reused, reducing the consumption of resources, production activities and energy otherwise needed to manufacture new systems with similar attributes, also minimizing greenhouse gas emissions (GHG) [2]. Furthermore, as refurbished systems are more affordable than new medical devices, refurbishing also contributes to increase healthcare access by allowing hospitals and healthcare providers with budgeting constraints to acquire high quality equipment [2]. It can be concluded that refurbishing 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) [3].

The refurbishment of medical systems addressed in this paper is described by a 5-step Quality Process, as illustrated in **Figure 1**, returning a used system to like-new

condition with the company's Proven Excellence Quality stamp and the fulfilment of the NEMA/MITA<sup>12</sup> standard for refurbishment, as well as the ISO 13485, ISO 14001 and OHSAS 18001 standards: 1) Selection, 2) De-installation, 3) Refurbishment, 4) Installation, and 5) Services. The third step, Refurbishment, encompasses 6 other operations: Incoming Inspection, Spare Parts Harvesting, Cleaning and Disinfection, Equipment Reprocessing, Reassembly and Final Testing, and Packaging of the final refurbished system. The focus of this paper is the Spare Parts Harvesting (SPH), process through which parts are retrieved from the medical systems in order to assist customers, for instance, in repairs and warranty services, or to be incorporated (reassembled) in new refurbished systems. The process is currently identified as inefficient, characterized by non-value-added activities, information, space and motion wastes, and lack of standardization.

Since remanufacturing industries are subject to great uncertainty 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 [4], the implementation of lean methodologies, tools and practices within this context is investigated. In fact, one of the major challenges to lean implementation in remanufacturing industries is the requirement for a reverse logistic network [5]. In addition, the remanufacturing process incorporates activities which are exclusive to this industry, such as disassembly, cleaning,

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<sup>1</sup> NEMA/MITA 1-2015 Good Refurbishment Practices for Medical Imaging Equipment

<sup>2</sup> MITA: Medical Imaging & Technology Alliance – a Division of NEMA: National Electrical Manufacturers Association

inspection and sorting, adding complexity to this system ([6], [7], [8], [9]).



Figure 1. 5-Step Quality process to refurbish a medical system according to the case-study company, and in accordance with the NEMA/MITA standard for refurbishment.

### 1.1. Objective

The main goal of this work is to improve the SPH process, investigating whether lean methodologies, tools and practices can be applied to improve its productivity and efficiency, reduce process lead-time, eliminate non-value-added activities and wastes, and achieve process standardization, contributing to the company's sustainable development goals.

### 1.2. Structure

The paper is divided in 8 chapters:

In chapter 1, the problem is contextualized within sustainable development goals and the objective for the paper presented.

In chapter 2, the existent literature on the theme is reviewed, relevant concepts clarified, and lean methodologies, tools and practices successfully implemented in remanufacturing companies presented.

In chapter 3, the case-study is introduced.

In chapter 4, the identified challenges are described.

In chapter 5, the developed methodological approach is presented.

In chapter 6, the lean tools, methodologies, and practices reviewed during chapter 2 are developed and implemented in the case-study.

In chapter 7, the achieved results are evaluated and discussed.

Chapter 8 is where the final conclusions and future work are presented.

## 2. Literature review

### 2.1. Motives for product recovery

Many authors place the causes for product recovery in legal, economic and social drivers (for example [7], [10], [11]). Repair, refurbishing, remanufacturing,

cannibalization, and recycling are product recovery solutions [10]. Cannibalization is described as sets of reusable parts from used products that are purposely recovered for repairing, refurbishing or remanufacturing other products [10], description that corresponds to the Spare Parts Harvesting process addressed in this paper. A terminology ambiguity regarding remanufacturing and refurbishing concepts was identified. Kumar and Putnam (2008) described the focus on recovery of resources, recycling and reuse as “cradle-to-cradle” resource management [12].

Contrary to what is usually pointed out in the literature, Seitz (2007) presented predominant motivators that lead companies engaging in remanufacturing, and include securing spare parts supply and warranty, protecting market share and brand image, and enhancing customer orientation [13]. These motives were also perceived in the case-study company.

### 2.2. Impact of spare parts businesses and associated challenges

The business of spare parts has economic relevance for companies. Cohen, Agrawal and Agrawal (2006) realized 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” [14]. The spare parts business consists of four main functions: sales and delivery, purchasing, warehousing, and product data management [15]. Suomala, Sievänen and Paranko (2002) 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 [15]. 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, et al. (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 [16]. Moreover, around 23% of parts become obsolete every year [14], which makes it especially difficult to balance inventory levels with obsolescence and stockout costs [16].

### 2.3. Lean in remanufacturing industries

Remanufacturing industries have specific characteristics that distinguish them from the conventional production system, and which represent a greater challenge to the implementation of lean. Priyono and 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 [4]. 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.

Lean tools and methodologies usually employed to identify challenges in processes include Value Stream Mapping (VSM) and process mapping, and which help distinguishing between value-added and non-value-added activities, aiming to eliminate the latter ([17], [18], [19]). Also important is to investigate the root-causes of the symptoms revealed by the VSM, and one possible root-cause analysis tool is the Ishikawa diagram ([20], [18], [21]). Daily shopfloor meetings are also useful to identify problems by sharing ideas, concerns and provide feedback between managers and employees [8].

Dayi, Afsharzadeh and Mascle (2016) used the 5 lean principles (identify the value and the value stream, eliminate waste, create flow, respond to customer pull, strive for perfection) to successfully improve the disassembly process of an aircraft [22]. In the present paper, the first, second, third and fifth principles are particularly targeted. Layout for continuous flow was identified as a specific tool to improve process workflow and eliminate wastes in the workshop ([23], [24], [25]). Standard Operating Procedures (SOP), 5S, and visual management tools such as visual control are used to achieve improvements in quality management, FIFO (First In First Out) lanes for improvements in operations planning and scheduling, PDCA (Plan, Do, Check, Act) for continuous improvement, and supervision and mentorship for improving employee commitment and management [25]. It is concluded through literature review that the implementation of lean in a remanufacturing context has several benefits, which include reduction of lead-time (by implementing lean practices, Kurilova-Palisaitiene and Sundin (2014) discovered that the lead-time of a forklift truck remanufacturer could be reduced by 93% [19]), 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 ([8], [26]).

A gap in the literature was also found regarding the implementation of lean in spare parts harvesting processes, and for which this paper provides an academic contribution.

### **3. Case-study: Spare Parts Harvesting process**

This case-study was developed in a German engineering company inserted in the healthcare industry. For 6 months, the refurbishing process of medical systems was thoroughly observed and analysed, which allowed the characterization of the 5-Step Quality process, in particular the refurbishment step, which encompasses 6 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 refurbished system. The present case-study focused on the Spare Parts Harvesting (SPH) process. The SPH comprises 3 stages, the first stage concerning with the searching for the parts, the second stage with the disassembly of parts needed for stock and destruction of the remaining, and the third stage with cleaning the workshop.

The SPH workers receive the systems from the Incoming Inspection together with a requirements list, check all labels found inside the systems and take note of the respective part-number. Each part-number is then consulted in a different list, the spare parts list, to verify whether it is identified as a part to scrap (identified as “to discard”) or a part needed for stock (identified as “RS HP”, Refurbished Systems Harvested Parts). In this list, for each part-number found, the worker fulfils its revision and serial number indicated on the label. Then, if it is a part to scrap, the worker destroys the respective label and discards the part; if it is a part for stock, the part is disassembled from the system and temporarily stored in a material trolley, waiting for it to become full and then taken to the spare parts warehouse. Meanwhile, the spare parts list is sent to the Sourcing department, where each RS HP part-number the worker found on the system is checked on SAP to verify its inventory levels, last

warehouse entries and exits, and respective quantities. Upon this check-up, it is decided if it truly is necessary to keep more inventory of each of those part-numbers. If it is not necessary because there is enough stock, the RS HP terminology in the spare parts list on that specific part-number is changed to “to discard”. After going through all part-numbers on the list, it is sent back to the SPH workers. So, it might happen that a part first identified as needed for stock is discarded after all, and this confirmation only arrives after this processing by the Sourcing department. If this is the case, the SPH worker must destroy the label corresponding to that part-number (currently awaiting in the material trolley) and send the part to scrap. The process is completed, and the workshop cleaned to receive the next system. These medical systems can be of two natures: biplane systems (large medical systems), and monoplane systems (smaller medical systems). The lead-time of the process for a biplane system is around 12 hours and for a monoplane system around 8 hours.

#### 4. Problem statement

The SPH is identified as an inefficient process with great potential to improve, where non-value-added operations and wastes were perceived. Eight challenges can be highlighted:

- I. **Outdated spare parts list.** This 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).
  - II. **Inadequate requirements list for the 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 refurbished 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.
  - III. **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 part-numbers found inside 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).
  - IV. **Decision to stock RS HP parts is done based on intuition.** When the Sourcing department receives the spare parts list fulfilled from the SPH process, the list is filtered to show only those part-numbers identified as RS HP (Refurbished Systems Harvested Parts, terminology used to identify parts needed for stock) and next it is checked when were those parts last booked from the warehouse and respective quantities. It is decided based on intuition whether is necessary to keep stock of those parts or not.
  - V. **Inefficient communication between cross-functional departments.** In the current state, the Sourcing department first sends the spare parts list to the SPH workers (a new unfilled list is sent for every system), which after fulfilled is sent back. Then, the Sourcing department 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.
  - VI. **Spare parts lost along the process.** This problem is a consequence of the outdated spare parts list, because Customer Service is requiring parts (identifying them in a 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.
  - VII. **Motion and space inefficiencies.** The SPH workers bring the several parts of a system in 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.
  - VIII. **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 is best.

The objective of this work is then to improve the Spare Parts Harvesting process by overcoming the identified challenges.

### 5. Methodological approach

The process improvement followed a 3-step methodological approach, based on Kurilova-Palisaitiene (2018), as illustrated in **Figure 2** [25]: the first step had to do with preparation, that is, to collect as much information as possible of the 5-Step Quality Process to refurbish an end-of-life medical system, and especially of 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” ([25], [27]): 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 process mapping (first point in the execution step), with the objective of identifying all material and information flows in the 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) was performed, which aimed at identifying what was causing the low productivity in the Spare Parts Harvesting process. Finally, supported by literature review, the selected lean tools, methodologies and practices were implemented (SOP, visual management, layout for continuous flow, 5S, supervision and mentorship, continuous improvement) in

order to optimize the Spare Parts Harvesting process. 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 the new process.

### 6. Lean implementation

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 chapter starts by identifying challenges in the process resorting to lean tools in section 6.1, followed by the improvement and standardization of the work procedure in section 6.2, and finally the improvement and standardization of the workshop layout in section 6.3.

#### 6.1. Identified challenges and selected lean tools, methodologies and practices

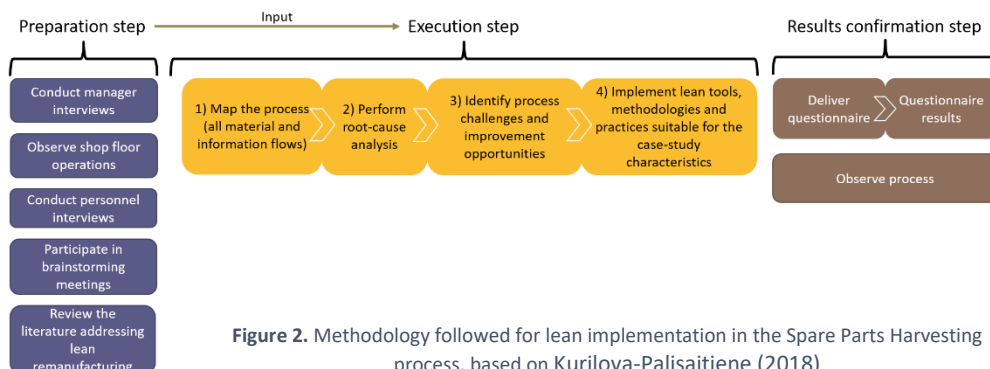
##### 6.1.1. Process mapping

By reviewing the literature, it was seen that process mapping is a suitable tool for identifying non-value-added activities in the process, in the way they describe the material and information flows along the value stream ([17], [18], [27]). Mapping the process by designing it is part of a visual management practice. A process map was developed as part of the first point of the execution step (**Figure 2**) to study the material and information flow in the Spare Parts Harvesting process, and is illustrated in **Figure 3**.

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 are outdated and inadequate to the process, making the searching for the parts much more difficult.

The second red star highlights the checking of all labels inside the medical systems and signalize them in the requirements list because this is a non-value-added



**Figure 2.** Methodology followed for lean implementation in the Spare Parts Harvesting process, based on Kurilova-Palisaitiene (2018)

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 spare parts list 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 turn to 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 (the data pool 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 the Sourcing department 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, identifying right away all the parts needed for stock in a given period of time.

### 6.1.2. 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 diagram was selected based on literature review ([8], [20]) and the result is illustrated in **Figure 4**, where five main problem categories were identified as impacting the current low productivity in the SPH process: method, machine, manpower, material and environment.

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 3**. 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 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 the Sourcing department, 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.

### 6.2. Work procedure improvement and standardization

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

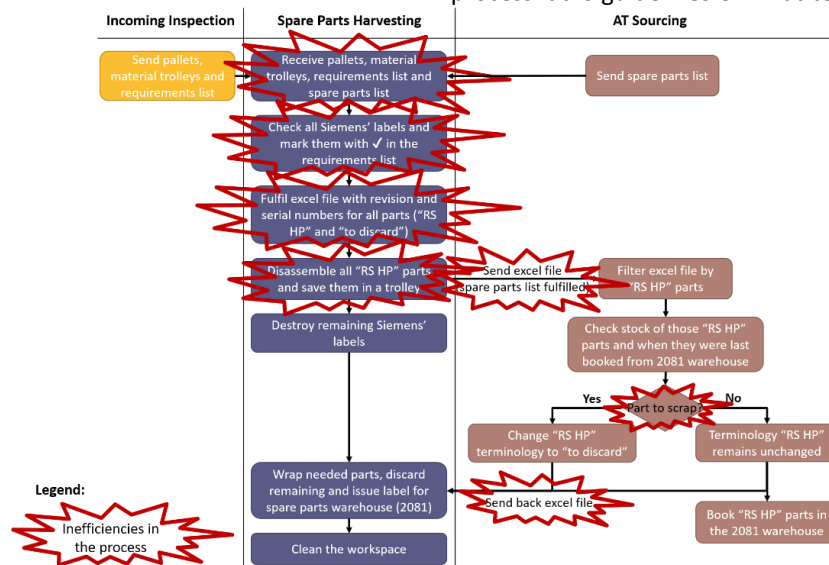


Figure 3. Spare Parts Harvesting process map

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) ([8], [25]). To accomplish that, the whole process was reformulated and restructured, starting with the spare parts list.

The first stage to improve the spare parts list was to update it, resorting to the master data pool file, an excel file of the Customer Service (CS) responsibility, which identifies all part-numbers that must be kept in stock as part of warranty services (for example, it is the company’s policy to ensure spare parts availability for refurbished systems for a minimum period of 5 years). This data pool file was filter 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. With this update, the spare parts list was reduced from 2,011 to 168 part-numbers.

This new list was organized by system’s name and showing all part-numbers belonging to that system which are required for harvesting. In the end, it looked like a catalogue, reason why it was renamed spare parts catalogue. It was established that the catalogue must be updated every month resorting to the data pool file. This new catalogue identifies right away all part-numbers that are actually needed for harvesting, avoiding the excess exchange of e-mails to confirm this situation. The communication between cross-functional departments is instantly improved and more efficient.

Regarding the requirements list, a new column was added to support the SPH workers, and it automatically inserts a mark if the part-number on the list corresponds to a part-number on the spare parts catalogue (by doing a cross-check).

Finally, a new list was created so that the SPH workers can fill it out with all parts that were disassembled from the system, the disassembly list.

For each new system received in the process, the Sourcing department sends the spare parts catalogue, the requirements list and the disassembly list all together, and the SPH workers have all the necessary information to perform their job. In the end, they only need to send back the disassembly list, so that the Sourcing department can give entry of those part-numbers in the spare parts warehouse.

This work procedure improvement used the notions of the 5 lean principles, particularly principle 1 (identify the value and the value stream), principle 2 (eliminate waste), and principle 3 (create flow). Moreover, the process is now fully standardized and all procedures well documented, informing what and how to do the SPH, creating Standard Operating Procedures for the process.

### 6.3. Workshop 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. To achieve improvements at this level, it was necessary to first carry out a capacity study and a material flow analysis inside the workshop, which allowed the development of layout suggestions, and the selection of the best option.

#### 6.3.1. Capacity and material flows analysis

The SPH for AT systems is an area of 100 m<sup>2</sup>. 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. 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). 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.

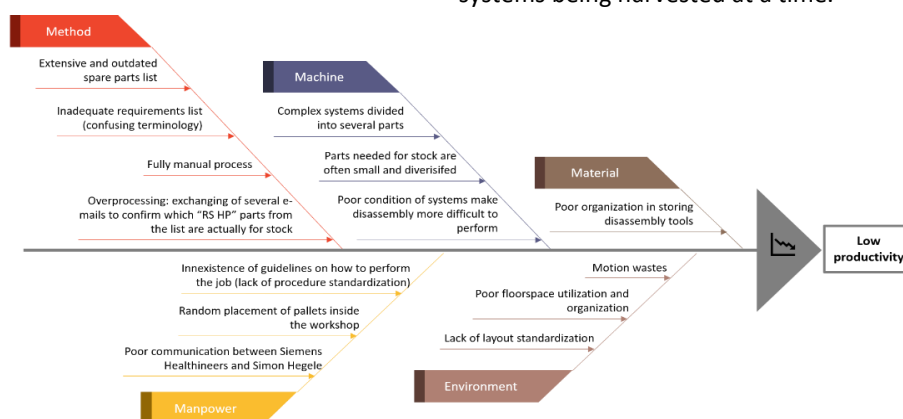


Figure 4. Root-cause analysis of the low productivity in the SPH process using the Ishikawa diagram tool

Taking this into account, **Table 1** presents the possible combinations of every 2 systems that can be received in the area: the most common situation is 2 monoplane systems (mono.) 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 (bi.) – 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”.

It is possible to conclude that there can be up to 24 pallets at a time in the 100 m<sup>2</sup> 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 wastes of motion.

**Table 1.** Capacity study per possible combinations of medical systems received

		Possible combinations	
		Capacity study	
		Pallets	Trolleys
Often	2x Mono.	12-16 (~14)	2-4 (~3)
	1x Mono. 1x Bi.	14-20 (~17)	3-5 (~4)
Rarely	2x Bi.	16-24 (~20)	4-6 (~5)

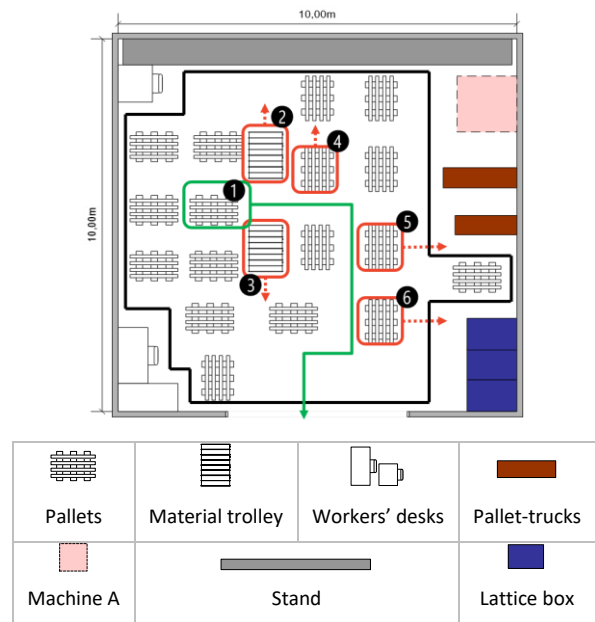
### 6.3.2. Layout developments

The following step was to develop the current layout status, illustrated in **Figure 5**, 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:

- 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 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.

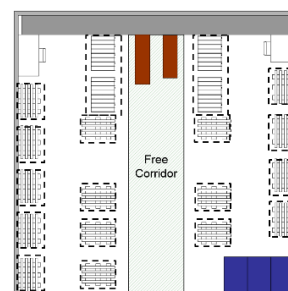
The machine occupies a large area of useful space and it should be removed.



**Figure 5.** Before SPH layout and material flow analysis

- As it can be seen through **Figure 5**, 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, one layout suggestion was developed considering lean methodologies 5S, Visual Management tools (specifically Visual Control) and Layout for Continuous Flow ([8], [22], [23], [24], [25]), illustrated in **Figure 6**.



**Figure 6.** Layout suggestion development



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. 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.

The **5S** methodology was chosen based on the work by Pawlik, Ijomah and Corney (2013) and Kurilova-Palisaitiene (2018) [8], [25]. 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 [28]: “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 3 S’s, and discipline means always following specified and standardized procedures [28]. 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. 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 SPH process will be continuously monitored resorting to the PDCA cycle in order to comply with the fifth lean principle, pursuit perfection.

## 7. Results and discussion

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; communication between cross-functional departments 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 all these results confirm that standardization was achieved across the process. 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.

## 8. Conclusions and future work

This paper addressed the Spare Parts Harvesting (SPH) process of medical systems. The process was identified as inefficient and characterized by wastes and lack of standardization. These were the focus of the paper and concerned work procedure and workshop layout related challenges. The goal was to overcome them resorting to

lean methodologies due to their well-documented impact on processes improvement.

The implemented improvements allowed an average 40% lead-time reduction, as well as a fully standardized process. Besides, new parts are harvested and unneeded parts scrapped, 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.

Since the SPH 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. It is suggested to, besides sorting parts based on their condition, to also sort them by whether or not they contain spare parts, delivering in the SPH process only those systems' parts known to contain spare parts inside, further improving both processes. This suggestion was thought taking into account the lean methodology SMED (Single Minute Exchange of Die).

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