UNIVERSITAT DE BARCELONA

Final Degree Project

Biomedical Engineering Degree

Logistics Improvement Strategy for Medical Units following the Lean Approach

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Author: Cristina Claudia Knill

Director: Eugeni Freixas

Co-Director: Rosa Oliveras

Tutor: Manel Puig

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Cristina Claudia Knill

ABSTRACT

The logistics portrayed in medical environments is a field which is not usually visible towards patients, but directly affects the health service quality, so it is a very important aspect for healthcare organizations to take into account. Hospital logistics are in charge of managing the supply of drugs, equipment, materials, laundry and sometimes even the food catering, through transport, storing and heavy organization skills.

This final degree project focuses on the elaboration of a new scheme for improving the logistics set behind Hospital Clinics' medical units, this being the management and supply chain of medical material and other items the hospital makes use of, by adopting more sophisticated technology. The improvement plan basically comes down to automating the systems used in the warehouse and storage rooms by using the popular Lean approach designed by the Japanese Toyota company in the mid 90s.

In the paper, several Lean management and healthcare techniques are used - to study, analyse and advance the current logistics, the goal is to automate the main warehouse with robotic load systems and to pre set the current faulty Kanban used in the storage rooms with a new and improved Smart Kanban technique, based on radiofrequency and more advanced technology.

The project verifies the necessity of biomedical engineers to not only provide a critical engineering point of view towards the systems used in hospital environments, but also to improve the lack of communication between the logistics team and the rest of the medical departments, which is a serious issue.

Keywords*:* *Logistics* - *Lean - Kanban - Automation - Muda - Load - System - Supply chain - Inventory - Ergonomics*

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1. INTRODUCTION

The growth of the aging population particularly in Europe, contributes to an increase in the Healthcare system workload. To guarantee the required level of healthcare, the logistics behind everything has to be efficiently coordinated to ensure a continuous quality of service. Statistics indicate that the number of patients in hospitals is increasing rapidly in western countries, which consequently rises the load of logistics functions [1].

Logistics is basically a planning orientation and framework that seeks to build a plan for the flow of product or information between the point of origin and the point of consumption in order to meet customer or corporation requirements. Supply chain management builds upon this framework in order to be linked to all the processes [4]. The cost of logistic activities in the medical field is invisible towards not only the patients, but towards the majority of the hospital. Society in general is unaware of what goes on in the numerous purchasing departments, general warehouses, storage rooms, ordering and delivery systems, etc. which produce a large number of expenses and somehow never manage to obtain satisfaction, especially from the clinical personnel (doctors, nurses, assistants, etc.) [2].

Many different strategies have been described and designed for hospital or healthcare logistics, the popular Lean approach which was created by the Japanese Toyota company in the mid 1950s, kicked off a few decades ago in Northern America and Europe followed up. Today, the Lean hospital model is applied in 24 locations of Spain, according to the Catalan *KaiLean* company who focuses on Lean applications. The Lean methodology, is basically a scheme that follows the principle of Just-in-time (JIT), which in its essence basically means to always get to as close as possible to zero-inventory or producing exactly the right item at exactly the right time [3].

It is no surprise that the development of logistics services in medical activities is applying the most advanced technological achievements amongst information technologies supported by management, maintenance-free means of transport, automated transport and technologies of automatic identification [1]. Logistics is indeed a branch of engineering which is in constant renovation and movement, so the inclusion of high tech is always a must.

The paper presents an improvement plan for the current material management strategy used in Hospital Clinic (Barcelona, Spain), using the modern forms of logistics a hospital of such prestige should hold. A significant share of attention is devoted to Lean management techniques and tools to elaborate the improvement scheme.

1.1. Objectives

- Goals

The goal this final project holds is that of increasing Hospital Clinics' efficiency centred in the logistics set behind medical supplies, to achieve a better optimization which will be reflected on the rest of the hospital providing patients with a better satisfaction, this therefore comes down to the concept of automating systems.

The strategy plan can be divided into two matters:

- Warehouse automation
- Storage room automation

The point is to redesign the management logistics done in the main warehouse (Cornellà, Spain) by using more sophisticated technology and Lean management techniques in order to increase productivity, space optimization (to store more items), etc. as well as redesigning the basic Lean Kanban system currently used in the hospital storage rooms, with wireless technology. By making both facilities be communicated via radiofrequency, we will therefore eliminate various procedures which are currently being used, and in other words, we will be reducing expenses and incrementing efficiency in the processes.

- Motivation

The whole project motivation comes down to a personal drive in the logistic hospital ambiance as a response to the need of improving medical optimization - in other terms, the need of automating medical organization in a more structured manner, by making it faster, more organized and more cost-effective. Also, the awareness of knowing that something needs to be fixed from the bottom, in order to improve the whole output, without forgetting about the future prospective.

Additionally, having a full understanding of Lean methodology is also relevant, not only to comprehend the Kanban method used in hospital storage rooms to improve it, but also because Lean management is a very solid technique used worldwide for the logistics of a wide range of disciplines.

Another reason for a personal interest in this field is that of having a wholesome economical understanding on the financial side of biomedical material, for future relevant goals.

1.2. Scope and Span

Automation is a key aspect in the future of health systems. In this project we have done a thorough analysis on the current systems used in the Hospitals storage rooms and in the general warehouse, understanding its functionality, advantages, disadvantages and most importantly, studying all from an economic point of view, as the whole idea of this improvement plan is about optimizing the systems, in other words, increasing quality and reducing expenses. So, for this reason the Lean methodology is picture-perfect to be put into use under this circumstance. The project focuses mostly on the general warehouse and storage rooms as they are the two connected systems in cascade and are relevant to be improved (Figure 1). The systems (S1 and S2) are connected, because the first system's input (X1), being all the inventory supplied by different providers, is stocked in the general warehouse (S1) until ordered, then the flow of the output (Y1) is sent to each medical entity, this being (S2). Here the warehouse output becomes the storage rooms input (X2) which is stored in each storage room, ready to be consumed (Y2) using the Kanban method.

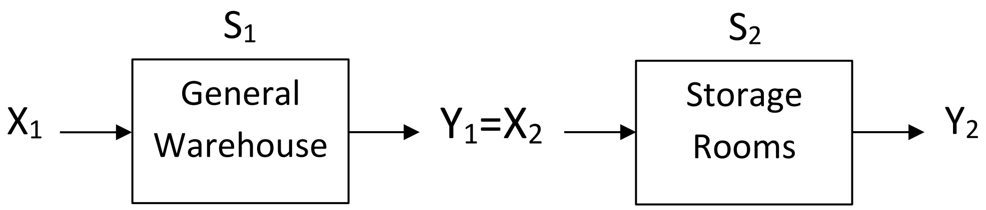


Figure 1. Connected systems: Warehouse and Storage rooms

The logistics improvement plan required a pre-analysis of the current situation: collection of data and observing all the processes with help of the Lean tools. The data was studied and realized using Microsoft Excel, for creating tables and obtaining simple statistic results; Rstudio, for statistical functions analysis; *Systems, Applications & Products in Data processing* (SAP) software to acquire all the logistics data happening in the hospital (material being ordered, expenses, etc.) and Edraw, which was used for the purpose of applying the Lean methodology.

Hospital Clinic and the University of Barcelona are collaborating together in this scheme, where this particular final year project will be useful for medical optimization improvements in the warehouses and storage rooms for both fungible (one-use-only) and non-fungible material. If the modifications turn out positive, then there will be a chain reaction in the rest of the medical departments, making this project be of a major responsibility. Hospital Clinic as does many other hospitals internationally, uses the Lean healthcare system, which is the system we shall base ourselves on. We will be working in the General service department and the logistics department of hospital Clinic. It will be made up of very hands-on tasks, to get more than a glimpse of what needs refining.

The project bases itself on 240 hours of an internship in Hospital Clinics Logistics department and 300 extra hours of further analysis and research. The plan commenced after experiencing situations in the warehouse and storage rooms, which noticeably required altering.

1.3. Methodology

The paper describing Hospital Clinics strategic improvement plan has been structured into 5 stages and can be viewed in the flowchart below (Figure 2).

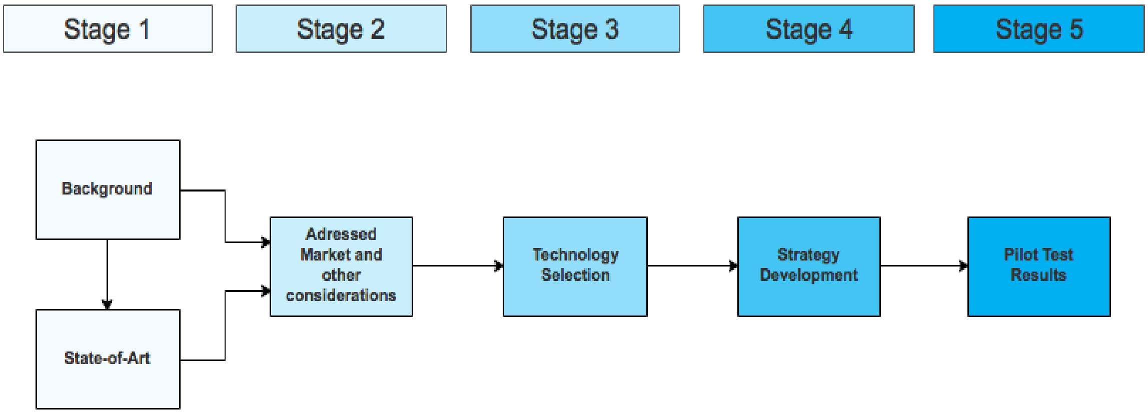


Figure 2. Methodology flow chart

Stage 1: Background and state of art. The current logistics implied in Hospital Clinics material supply chain is described in section 2.2, where the situation in the warehouse and storage rooms is explained with the used technology in each case. The Lean approach which will be followed for the plan elaboration along with the Kanban system is described in detail in section 2.4, as well as technological alternatives to be considered.

Stage 2: Addressed market and other considerations. The users of the new systems, aimed at nurses and operators is described in section 3.1 and the legal aspects to take into account are stated in section 4.

Stage 3: Selection of technology and strategies. The technology chosen for the new strategy is described in section 5, with the *load systems* for the warehouse in section 5.2.1 and the *Smart Kanban* for the storage rooms in section 5.2.2.

Stage 4: Strategy development using Lean approach. The plan is designed after doing a thorough analysis of the systems using the Lean techniques explained in section 6.1, with an experimental validation in section 6.2. The project design is summed up in section 6.2.3.

Stage 5: Experimental results and strategy validation. Statistic data is provided to backup the strategic improvement plan, with the results in section 6.2.2 and the economic feasibility explained in section 7.2.

2. BACKGROUND

Grasping a wholesome idea of the product background is also important to acknowledge when wanting to improve a system. In this case, the product is all about the logistics systems reflected in Hospital Clinic.

2.1 Antecedents

The original hospital was built around University of Barcelona's medicine faculty, due to a physical necessity of patients so that the students could practice on and so was founded in 1906. Since then, the hospital has grown massively and extended itself all around Barcelona, leading the hospital to build a general warehouse, to stock material for all the hospitals different buildings around the city [23].

Before the existence of the general warehouse in Cornella, all the hospitals material was accumulated in what was the main storage area in Hospital Clinic, which is now used as a transit area (100m^2) due to its lack of space.

The hospital has been using the Kanban or double-compartment system for their material management since 2004. Before Kanban hospitals used to get by, by having to rely on a staff member in charge of ordering supplies to operate on *gut instinct*, with no data what so ever. The result was that for certain supplies, availability was limited, and many employees felt the need to reserve supplies so they could access the items they needed to care for their patients. For other supplies, the stockrooms were overflowing, taking up space that could have been used for patient care. So basically it was chaotic for a number of reasons as well as a pricey way of malfunctioning. In some ways many of these issues still come up and need to be abolished.

2.2. Current state of the situation

1. Warehouse situation

The general warehouse is a space of 589m^2 that currently stores 260 pallets as well as items that fit into the carousel compartments. The warehouse stores and receives material to then deliver it to all Hospital Clinics entities. Material is currently divided into 2 types: Transit and Storage material:

- **Transit material:** Consists of material that is not kept as stock in the warehouse, in other words, material the hospital has punctually ordered for a certain event.

- **Storage material:** Is the everyday-usage material kept in stock to be delivered to the hospital. Within the storage material, inventory is divided into two types:
    - **Large Volume.** Boxes are stacked on pallets which are classified into three different aisles (A, B, C). Pallets are placed in correct locations using a forklift, which is controlled by an operator (Image 1). The delivery notes show exactly in what position each box should be placed in. The programme used to keep control of these items is the SAP software.

Image 1. Large volume

- **Small Volume.** Items smaller than 36000cm^3 are introduced into a carousel (Image 2), which is the only technology used along with the two software. A horizontal carousel is an automated storage and picking system which optimizes available space, it has the advantage of giving the possibility of multi-picking and multi-packing as it is coordinated with a programme, which in our case is called ULISES, this programme stores each items code and position and governs exactly what material has been received by reception and then shows it on a command.

Image 2. Small volume in Carousel

The warehouse uses two programmes, SAP and ULISES, both logistics software, which hold the commands with what material needs to be delivered to the hospital for the next day, ordered by the hospital itself. Deliveries are done by an external company and sent to Hospital Clinic's many entities (Hospital Clinic university hospital, maternity centre, IDIBAPS, CORE, dialysis centre, etc.).

Providers arrive in their vans to the warehouse entrance, then hand their delivery note which contains information on the material, quantity and company; to the reception, who enter all this information into SAP by hand. Then two operators located in the "work zone" separate transit from storage material by hand, to then be able to either stack the transit packages onto pallets to send off or store the storage material into either the large volume section (made up of aisles) or into the small volume section (made up of a carrousel with different compartments).

It is easy to conclude that the whole processing and management requires a lot of handwork and is old fashioned, as it all relies on the physical strength of stacking, picking and packing boxes from pallets, other that using more modern and efficient solutions, as well as the issue of using so much paper, which leads to human errors, occupies space and does not benefit the environment.

2. Storage room situation

Every medical unit is composed of a storage room and a control room (which is a smaller area that also some material), throughout the project we will include the control rooms with the storage rooms, because they have the same function, so both facilities will be referred to as "storage rooms". Hospital clinic includes a total of 66 medical units.

The medical units use the Kanban or two-bin methodology (also referred to as double compartment). Where each item is supposed to have two compartments (but due to space limitations some items only have one compartment); one for "in use" and the other one for never running out. When one compartment runs out of material, nurses pin the compartments label, known as a Kanban tag (indicating information on the material) onto a metallic structure to let the logistics office know that the compartment needs to be replaced with new material, this command goes into the SAP database and is sent to the Warehouse.

This command is done by a logistics operator, who has a Samsung mobile phone with a SAP application and bar-code reader, that reads all the Kanban tags the nurses have pinned up, for all the items which need replacing (Image 3). This method was introduced in 2004, but now needs to be replaced by higher tech, as it has become obsolete for numerous reasons.

Image 3. Operator reading Kanban tags.

This current system has a series of problems:

- **Lack of communication between departments:** Due to a lack of communication between departments, the nurses struggle to understand the concepts of having two different compartments per material, and that one is set for stock and the other for use; causing chaos as they end up just grabbing material from any compartment. As well as the fact, that some materials do not have a double compartment, making the whole situation confusing.

- Poor Kanban training: In some occasions the nurses either forget or do not have time to pin the tags up, causing the operator to have to waste up to 2 hours of constantly having to ask whether or not the nurses have done their tasks to be able to read the cards.

- No trust in the system. Nurses seem to be constantly worried that they will run out of material so they end up asking for double or sometimes triple the amount that they are supposed to, resulting in an excess of material, which in some occasions cannot be stored due to a physical lack of space. In some cases, nurses have ordered supply in bulk to keep as stock supply (Image 5).

- Poor inventory control. As there is a stock overflow, out of date material is a problem (image 9).

- Space limitation. The limitation of space makes the automation of the storage rooms a big challenge (Image 7).

- Misuse of the storage rooms. In some cases, the storage rooms are full of large medical devices and equipment occupying a tremendous amount of space, that should not be located in this area. This problem worsens the space limitation even more (Image 8).

- Technical issues. The operator reading the tags has to connect to the Wi-Fi in every hospital area to access the storage rooms, causing yet more time loss.

There is also a transit area in the underground floor of hospital Clinic where all the boxes coming from the warehouse are stacked onto pallets in the hallway until the operators take them to the medical units (Image 4). A problem is that a lot of material is just left there, as a result of not knowing what to do with it, such as Ebola equipment (Image 6).

Image 4. Main storage area in hospital used for transit. Pallets and boxes in the hall

Image 5. Storage room with massive overstock. Boxes everywhere

Image 6. Ebola material stored in main storage area in hospital occupying space

Image 7. Space limitation in storage rooms

Image 8. Storage room misuse, material that should not be stored there

Image 9. Out of date gloves found due to poor inventory control

So we can clearly support the idea of optimization, backed up by a good automation.

2.3. The Kanban kick-off

In September 2003 a pilot double compartment test was carried out in what was hospital clinics Pneumology department (unit 6-2), it was analysed and results were published on the 16th February 2004, after studying the system throughout the year. The outcome was favourable, as expenses went down noticeably and the Kanban system was established in all the departments.

The Kanban system was a way of automating the management of material in storage rooms, by keeping a better control of the amount of items in stock, as to never have an overstock, therefore, reducing expenses and increasing quality.

The study of the pilot test was done by comparing items individually and their expenses per month, due to the fact that without the Kanban system, nurses would order as many items as they thought necessary, bringing a vast amount of problems such as material expiring and running out of physical space to place the items.

Based on the Pneumology departments material consumption, cost-centre H7N20, the new Kanban system indeed reduced expenses. Except for the first month in September, which was when the test was implemented and they had to double the amount of each material, for the necessity of having double compartments, this explains the fact that the expense was of 4,299.59€, when the expense the year before was of 2,630.78€ (Annex 1).

Statistical computations were made based on this department for each item and showed that 16.44% had was the highest saved quantity and 7.50% was the lowest saved quantity, based on the expenses realized from 2001 to 2003, as shown in tables 1 and 2 below.

Average monthly consumption of request				
Year 2001	January to December	3,327.41	Period average	% of saved expenses based on the period average from 2001 to 2003.
Year 2002	January to December	3,651.68	3641.86	
Year 2003	January to August	3,946.50		
New system extrapolation	September 2003 to January 2004	3,043.19		-16.44%

Table 1. Lowest average monthly consumption of request

Average monthly consumption of request				
Year 2001	January to December	32,838.02	Period average	% of saved expenses based on the period average from 2001 to 2003.
Year 2002	January to December	2,761.45	2807.56	
Year 2003	January to August	2,823.19		
New system extrapolation	September 2003 to January 2004	2,597.07		-7.50%

Table 2. Highest average consumption of request

The Pneumology department spent 44,466.51€ in 2013, this meant that in the scenario of saving 16.44% in the best case, costs would drop down to 39,276.47€; whereas in the scenario of saving 7.50%, they would spend 42,099.50€. These statistical computations were applied to all the cost centres.

The accessories purchased to complement the Kanban system in a favourable way, were the software which cost 2,344.31€/year and the scanner to read the Kanban cards which can be broken down in the following way (Table 3):

Item	**Price**
Symbol PDT 6100	1,753.30€
NimH scanner PDT 6100 battery	100.38€
PDT 6100 charger holder	514.82€
Electric feeder:	25.00€
RS 232 Cable	20.00€
Total	**2,413.5€**

Table 3. Basic Kanban accessory prices

So the cost of implementing Kanban basically doubled costs on its first month of implementation, but then reduced itself over the following months, therefore costs improved vastly.

2.4. State of Art

To evaluate the state of the art in the medical logistics field, a preliminary draft was developed in December 2016 for a subject called "Project engineering". The research was based on understanding the popular Lean approach which is used for supply chain management and the new technology used in warehouses and for Kanban applications.

2.4.1. Lean management

In the 1950s Japan was in throes of an economic depression. The occupying Americans were attacking inflation by restricting credit; car sales collapsed and loans became exhausted, Toyota faced bankruptcy [3]. So the Japanese acknowledged that they would have to renovate their manufacturing techniques significantly if they were ever going to climb up the world markets. Taiichi Ohno solved the problems by implementing the Toyota Production System (TPS), also referred to as "Lean production", which means doing more with less-lead time, less space, less human effort, less machinery, less materials-while giving customers what they want [6]. The company faced a massive transformation by demanding continual price reductions in part costs every year, in this way the Toyota system permeated the entire supply chain by the end of the 1970s [5].

The problems Toyota faced in the 1950s can easily be transposed to the problems we experience today: fragmented markets demanding many products in low volumes, tough competition, fixed or falling prices, rapidly changing technology, high capital cost and capable workers demanding higher levels of involvement, economic recessions, etc. [4] So Ohno's system is more relevant than ever. Today, the Japanese Lean system is defined as the strategy used to create and produce the highest possible value to a client, consuming as little resources as possible and using the knowledge of the persons' abilities who will be doing the job [7].

It is also necessary to describe the Lean system as a process of *pull* rather than *push.* Push means "make to stock" in which the production is not based on the actual demand; Pull on the other hand, means to "make to order" in which production is based on the actual demand. The pull type chain management is based on the demand side, so it follows the Just-in-time (JIT) idea, that is one of Lean's favourite principles [3].

The objective is to provide a suitable system, that provides a required level of output with a series of inputs. The figure below shows the systems view.

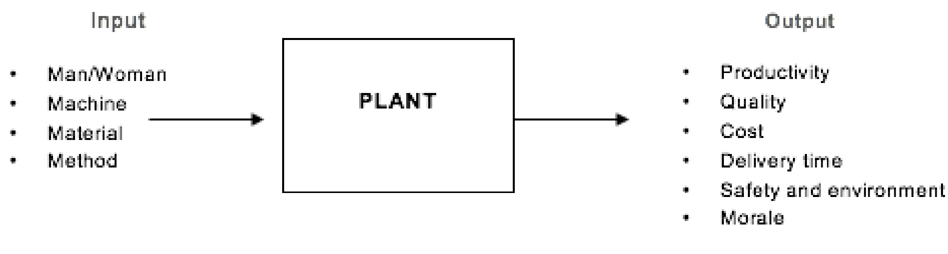


Figure 3. Lean management system diagram

Lean management has been widely applied in industries and is in a current boom within health systems, it is referred to as Lean healthcare [21]. The *Consorci Sanitari Integral* (CSI) implemented the *Gestió per Processos* (GPP), a management system for efficiency processes in 2001, but it was not until 2008 when Lean tools were implemented to improve efficiency in hospital ambiances. In November 2010 the CSI implemented the new methodology in its GPP, starting off in ambulatory rehabilitation processes in 3 different centres [22]. Studies show that significant improvements in costs are experienced after implementing the Lean methodology in health.

Lean mudas

The Lean goals consist in obtaining the best possible productivity, quality, cost, delivery time, safety and environment, and morale; Anything else, is considered a "muda". Muda means waste, or any activity which is not worth paying [6]. Mudas are the opposite of value, which is what we are willing to pay for. Summing up, the main goal is that of eliminating mudas, there is a remarkable 5/95 ratio of value to muda common in most operations, most of the day-to-day is muda. So we have to learn how to spot the mudas. The main mudas are described below in figure 4 [3]:

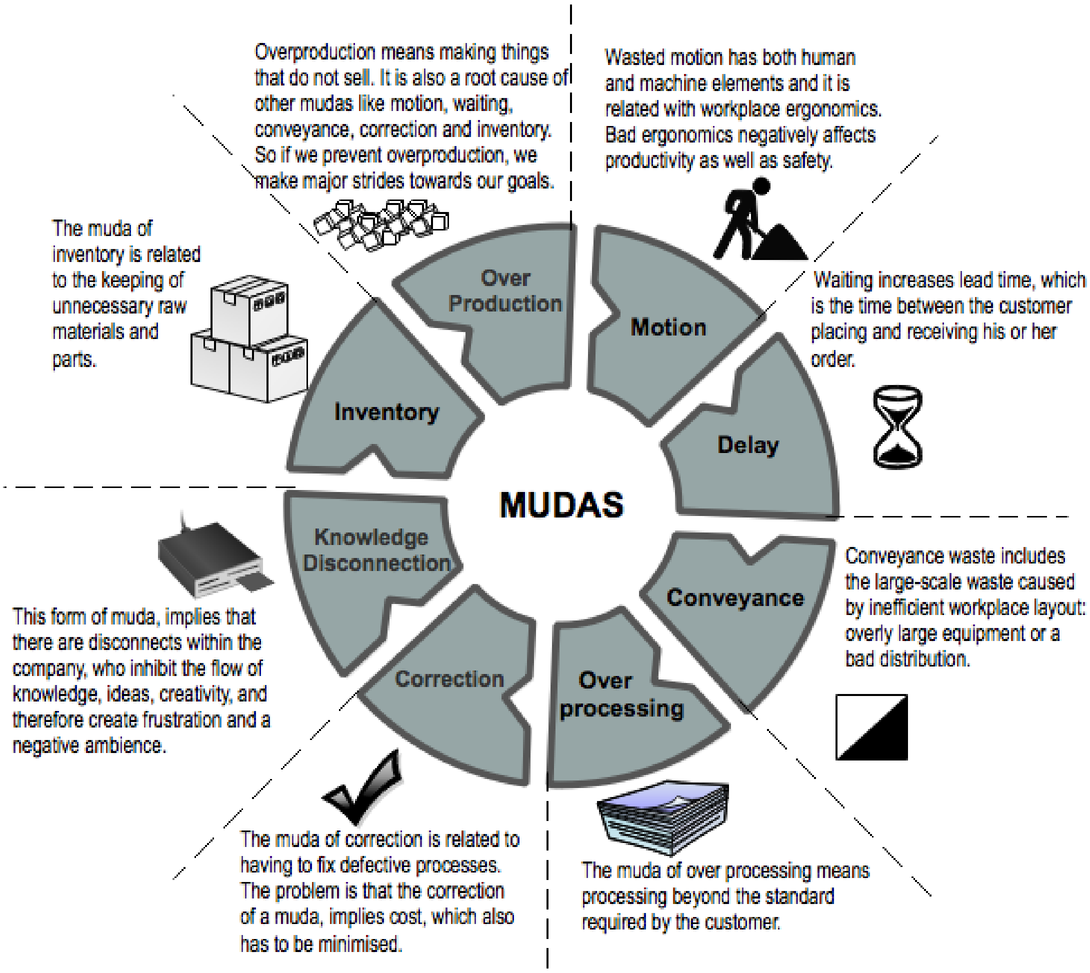


Figure 4. Lean Muda diagram

So all these mudas need to be identified and removed from the system, there are various Lean tools designed specifically for this matter, Lean tools are the source of continuous improvement, because whilst you improve a process, new mudas arise.

Lean tools

There are numerous Lean tools designed to identify and eliminate mudas and to improve the system (Figure 5), we will describe a few of them.

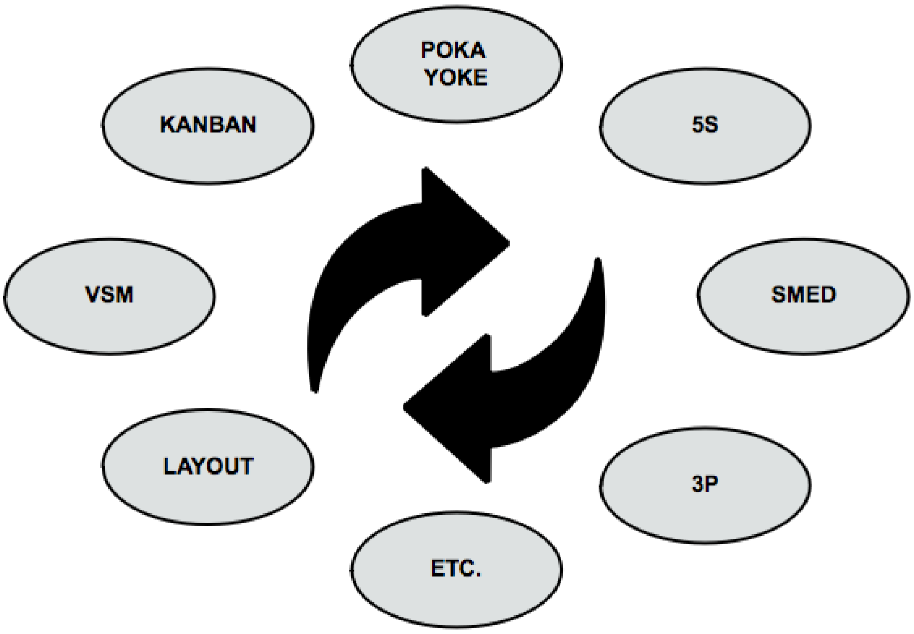


Figure 5. Lean tools diagram

- **The 5S system:** 5S is derived from five Japanese words starting with the letter *S,* which describe the principles of good house keeping [7]. It basically means that a clean and tidy workplace, is the foundation of improvement, the 5-S tool is described in table 4.

S1 - Sort	Consists in throwing out everything that has no value. If unsure, the red tagging technique is used where a red sticker is stuck to items and then the team discusses its value.
S2 - Set in order	Consists in organizing, rationalizing locations, applying colours, creating visual systems to make everything more ordered.
S3 - Shine	Consists in cleaning the workplace as well as inspecting changes in sound, aspect, smell, vibrations, temperatures or other *bad* signs.
S4 - Standardize	Consists in making sure the work place, stays in that manner. S4 is also related to avoiding the muda of overproduction.
S5 - Sustain	The objective of S5 is to maintain the workspace organized. Promotion, communication and training are musts.

Table 4. 5-S Lean tool explained

- **Value Stream Mapping (VSM):** Value Stream Mapping [11] is a valuable tool that allows us to grasp a sense of the current situation to identify mudas and improvement opportunities [12]. VSM is a language made up of symbols [13] The symbols legend can be seen in Annex: figure 1. The concept of Kaizen comes in here, which are symbolized as *spikey clouds* and they represent opportunity ideas. VSM is very useful for finding which processes take the longest, if it can be shortened or if various procedures can be modified or eliminated.
- **Layout.** Layouts trace al the movement flows of a component/material in a simple design.

There are many other Lean tools, but in this paper we will be focusing on the described tools above and more importantly, the Kanban tool.

- **Kanban.** Kanban is a visual tool used to achieve JIT production [15]. It is usually physically represented by a rectangular card or tag. A Kanban is an authorization to produce or withdraw a product and it may also contain information on the product name, position of storage, how to transport it, the consumer, the quantity, etc. [3].

Image 10. Kanban tag example

Hospital Clinic Kanban tags have the following information as portrayed in image 10:

- ✓ Name of item
- ✓ Number of item
- ✓ Quantity
- ✓ Department
- ✓ Position in medical unit
- ✓ Bar code

In this project we will be focusing on the Kanban-double compartment or two bin system, the technique works in the following manner (Figure 7).

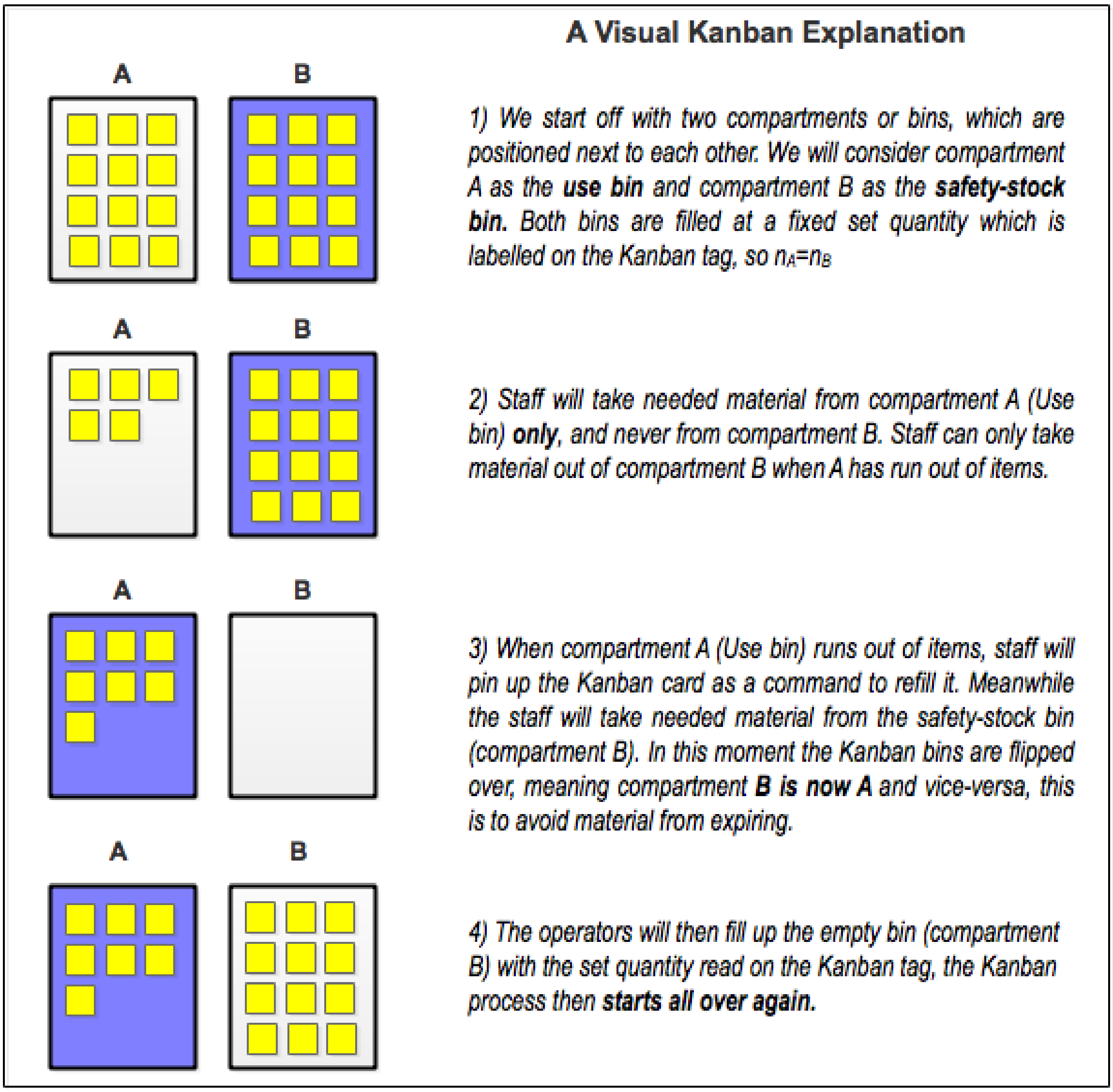


Figure 7. Kanban double compartment explanation

The process then starts all over again, the only difference is that compartments A and B have been flipped over. The Kanban objective is to never run out of material but also to never overstock.

Kanban quantities are calculated with the following expression [11]:

$$\text{Kanban Quantity} = \frac{Dc \cdot Q \cdot R}{H \cdot S \cdot P}$$

Dc: Daily capacity of product based on demand
Q: Spend quantity
R: Replenishment time (hours) according to strategy
S: Shifts per day in storage room
H: Replenishment time in hours
P: Parts contained in the package from the supplier

Expression 1. Kanban quantity formula

Kanban has many advantages such as preventing over production, preventing running out of material, reducing staff stress level, increasing visual understanding, lowering error rates from the human factor, improving teamwork and improving the work flow [12]. Yet, implementing Kanban correctly is indeed a challenge. it becomes far more complex when it comes down to [3]:

- Stock dimensioning
- Rotation turns
- Volume identification
- Reposition analysis
- Location analysis

Although Lean principles are rooted in manufacturing, they can be applied universally and are vastly growing in sanitary systems (Lean Healthcare*)*, which is defined as a model that centres itself on the reduction of waste and focuses on the flux of patient value. The methodology Lean healthcare follows consists in using a series of the Lean tools to identify and eliminate waste or mudas, just the same as in Lean production.

2.4.2. Technology behind Kanban

Implementing Kanban properly is a huge challenge, so automating the system should help the technique be more successful. These are the following forms of Kanban:

- **Manual Kanban.** A staff member manually notes down the empty compartments Kanban tag information (name, code, quantity, etc.) on an order sheet for it to be replenished.
- **Barcode Kanban**. The Kanban tag has a barcode, so when it is empty an operator scans the barcode which sends the information to the logistics software, for the items to be replenished.
- **RFID Kanban.** The Kanban cards have radio frequency identification (RFID) tags. RFID technology consists of using electromagnetic waves to access stored data in a microchip, that is paired to an antenna [9] - so when the compartment is empty, the card is placed near the sensor and a radio transmission of the item and bin data goes directly to the production department. This automation implies no need for scanning or manual entry of orders.
- **Robotic Kanban.** This new Kanban application is still being studied, but it would mean that the system would automatically know when a container has become empty without doing anything. For example, ADAM™ is a category that defines AMR (Autonomous Mobile Robot) that performs fully robotic, random origin to random destination transport of materials in Lean manufacturing operations, such as in Kanban processes [13].

2.4.3. Technology behind warehousing

The level of sophistication of medical warehouses varies widely, as there is a broad range of technology which can be implemented to suit each system nicely. The idea of a manual warehouse has become historic due to the fact that automation is the main key of logistics and supply chains, in most cases the more automation in processes, the more efficient they become. So this is why robots are becoming an important part of improving automated systems in warehousing.

Innovation in warehousing includes a variety of technology such as the inclusion of big data with Electronic Data Interchange (EDI) communication, drones for scanning codes, lithium-ion batteries with longer lives, Radiofrequency identification (RFID), robots, cloud storage and many more [16].

The main technology used for warehousing are the following:

- **Industrial Carousels**

An industrial carousel is an automated storage and retrieval device that uses shelving units mounted on a closed loop track. It is connected to a computer device, so that when commanded, the shelves rotate along the track and bring items to be picked or packed. There are two main types of carousels [13]:

- Horizontal Industrial Carousel: Is made up of a series of bins or compartments which are mounted on an oval track.
- Vertical Industrial Carousel: Is made up of a series of bins or compartments which are mounted to a vertical oval track inside a large cabinet.

The horizontal carousels are cheaper than the vertical ones on a 40/60 based ratio, though the vertical carousels have a higher storage density and space optimization. The horizontal carousels have higher picking rates than the other system and are almost perfect for batch packing. The plus side of the vertical carousel is that its ergonomics is better because operators do not have to bend or stretch to reach the products [13].

- **Rotating machinery**

Rotating machinery in its essence is an elongated structure supporting shelving units with shelves that stock packages where subassemblies move for loading and unloading the products and drop items in the picking area [19]. The system is similar to the horizontal carousel but is faster and holds better ergonomics, though it is generally used for small items such as in pharmaceuticals.

- **Load systems**

There are 3 types of load systems depending on the stored items [14]:

- **Unit-Load**: Move, store and retrieve pallet loads via RF.
- **Mini-Load**: Move, store and retrieve items in trays via RF.
- **Micro-Load**: Move, store and retrieve items in containers via RF.

Load systems are brilliant for optimizing space, as they are set in a 3D matrix-like manner, avoiding any empty spaces full of air. An automated warehouse comprises lateral pairs of racks that store articles in either pallets, trays or containers. Between the racks there is path that contains a forklift which finds the article via RF [18].

- **Amazon robots**

Several worldwide robot manufacturers, like Kiva (bought by Amazon in 2012 to become Amazon Robotics), Swiss log and Grenzebcack offer robotic solutions that make inventory, picking and packing faster.

The Amazon robots are designed to move materials around within warehouses, rather than having operators roaming the aisles picking items, the amazon robots simply zip underneath a pallet of shelving unit, lift it and bring it directly to an operator sat down at a picking/packing table. The robots navigate autonomously using a laid out grid that has barcodes attached to the floor [17].

3. MARKET ANALYSIS

3.1. Potential users

The potential users of this new logistics strategy is mainly aimed at Hospital Clinics logistics team and nurse department, though the outcome if correctly implemented, will be reflected in the costs department, so therefore, on the whole hospital, contributing to a satisfactory reaction from patients.

By automating the warehouse and storage rooms, users will benefit in the following manners:

1. Automated Warehouse:

- Less physical harm risks
- Easier usage
- Less error rates
- Less physical effort
- More safety

2. Automated Storage rooms:

- Better organization (visual systems)
- Better stock control
- Easier usage
- Less stress
- Less physical effort

3.2. Future market prospective

The rise of robotic systems is indeed a reality, due to the fact that they have excellent computing power, memory, precision, speed and many other advantages, rather than relying on people who will always have a higher error rate, have physiological necessities, will take longer, be less precise and many other unfortunate disadvantages with regards to robots. Also, with the Lean approach becoming more and more popular within Europe, its application in healthcare is perfectly compatible with robotic systems in warehouses, as well as its Kanban application in the storage rooms in the hospital environments. Therefore, health logistics is a main target for automation, though implementing completely robotic systems in health still need further studies and findings for it to be totally executed in medical environments.

Furthermore, professional comfort is another tendency in the medical field, where ergonomics is playing a very important role in Lean manufacturing. Ergonomics can help maximize work output by preventing physical harm and improving comfort, either from repetition, overload, awkward positions and others [24]. Due to this, systems are being designed with the idea of making the staff feel comfortable, hence, this comfort factor is reflected on their work, giving a more positive outcome to the objective of constantly improving efficiency.

4. NORMATIVE AND LEGAL ASPECTS

Hospital Clinics logistics department portrays the following main normative [20]:

1. Quality

- **ISO 9001:2008.** Certification for quality management systems following the norm UNE-EN ISO 9001. The certification demonstrates the ability of consistently providing product that meets customer needs following the regulatory requirements and aims to enhance customer satisfaction through the effective application of the system, including processes for continual improvement. The ISO indicates that the organization must have documented procedures for the following activities [25]:
    - Document control
    - Register control
    - Internal audit
    - Nonconforming product control
    - Corrective action
    - Preventive action

  This norm is applied for both warehouse and storage rooms.

- **ISO 9001:2015.** Certification for the control of the activities of development of controlled documentation. This certificate allows a greater flexibility according to the type of documentation with which it operates and controls its processes, as well as tries to eliminate the bureaucratic documentary. The documented information can be [25]:
    - In any format, (language, graphs, software...)
    - in any source, (estimations, calculations, expert judgement, documental references...)
    - in any medium, (paper, electronic...)

  This norm is applied for both the warehouse and storage rooms.

2. Labour risks

- **OSHAS 18001:2007.** Certification of prevention of labour risk, based on safety and security management systems (SGPRL). In Spain, the norm starts off with article 40.2 from the Spanish constitution where the public authorities have to promote a policy guaranteeing vocational training, occupational safety, limited working hours, paid holidays and promotion of suitable centres. This norm is only applied for the warehouse.

3. Environment

- **ISO 14001:2004.** Certificate of environmental management according to the norm UNE-EN ISO 14001. The norm will stop being valid by 2018, so it has to be updated to ISO 14001:2015. This norm is only applied for the warehouse.

4. Energy

- **ISO 50001:2011.** Certification of energy efficiency. The norm specifies requirements for establishing, implementing, maintaining and improving an energy management system, where the objective is to achieve continual improvement of energy performance, efficiency, usage and consumption. This norm is only applied for the warehouse.

5. Information security

- **ISO 27001:2005.** Certification of the information security management. The norm covers all types of organizations and specifies the requirements for establishing, implementing, operating, monitoring, reviewing, maintaining and improving a documented Information Security Management System within the context of an organization. It specifies requirements for the implementation of security controls customized to the needs of individual organizations or parts thereof. This norm is applied for both the general warehouse and storage rooms.

6. Packaging

- **ISO 3394.** Certification on box, pallet, platform and compartment dimensioning, for both length, width and heights. Measurements for individual exported product boxes also have to follow this criterion. This norm is applied both for the Warehouse and storage rooms.

5. CONCEPTION ENGINEERING

In this section we shall go into the conception engineering, in other words, we will study and propose the possible solutions to be implemented.

5.1. Study of solutions

5.1.1. Warehouse possible solution

Automated Storage & Retrieval (AS/RS) systems consist of a variety of computer controlled methods for automatically placing and retrieving loads from specific storage positions. AS/RS systems are typically used in operations with high volumes, facilities with space constraints and in applications that require extremely high accuracy and pick rates [15]. We will compare four AS/RS devices:

- **Load systems**
- **Carousels** (current)
- **Rotation systems**
- **Amazon robots**

All four AS/RS systems are favourable because they save space, reduce labour, increase productivity, increase accuracy, reduce inventory levels and enhance customer service. Obviously the Amazon robots are the most sophisticated, followed by the load systems, to the rotation and carousel systems.

5.1.2. Storage room possible solution

As the used Kanban system is currently failing in many aspects, we even considered other options, such as including massive vending machines with all the material, but then we realized that the items are far too heterogeneous for this idea, since the items need to have a certain weight and size.

We also studied the possibility of having a bar code reader by the entrance, so that whenever a nurse or doctor gets a hold of an item, they need to scan it with the reader hung by the entrance. The problem here is that not all items have a bar code individually, as many items are multiply packed into a box (bar code on box). This would be an issue, because we would have to make all product providers put a bar code on each item individually. Moreover, we would have the problem of staff forgetting to scan the items, increasing the human error rate.

A very useful application, would be display the Kanban bins in a different manner, instead of having the compartments positioned side by side, to have one on top of the other, with a flap in between each other. The staff can only take material from the bottom bin and when materials run out, all they have to do is pull the flap and material from the top will fall down. Problem is that this option is rapidly discarded due to the space limitation issue and the fact that Hospital Clinic's storage rooms have very low ceilings.

So we lastly decided to keep on studying Lean Kanban methods because of its growing relevance around first world. After browsing various companies through the Internet, we found four main scenarios of interest:

- **Manual Kanban**
- **Bar-code Kanban** (current)
- **Radiofrequency (RF) Kanban**
- **Robotic Kanban**

5.2. Proposed solutions

We have used the Lean six-sigma technique, which is generally used in manufacturing ambiences, but we thought the method ideal for finding the best solution. We did six-sigma for the warehouse and storage rooms.

5.2.1. Warehouse proposed solution

	Carousel	Load system	Rotatives	Amazon robots
Move pallets	0	3	0	3
move cubes	0	3	0	3
speed	1	3	2	3
precision	1	2	1	3
ergonomy	1	3	2	3
productivity	1	3	2	3
space exploitation	1	3	3	2
SAP compatibility	3	3	3	3
Economic	3	2	3	1

Figure 8. 6-Sigma table for warehouse solution

By observing the 6-sigma table above, the scoring system is as follows:

1. Carousel: 11 points
2. Load system: 26 points
3. Rotatives: 16 points
4. Amazon robots: 25 points

So the best system for Hospital Clinic is the load system. The point would be to include a Mini-Load system to substitute the current carousel, which moves cubes via RF towards the picking area; and a unit-load which also uses RF to move pallets towards the picking area.

5.2.2. Storage room proposed solution

	Manual Kanban	Bar-code Kanban	RF Kanban	Robotic Kanban
Control of inventory	1	2	3	3
Visual order	1	1	3	3
Easy-to-use	3	2	3	2
Space exploitation	2	2	2	3
SAP compatibility	0	3	3	3
Human error rate	1	2	2	2
Immediacy	1	2	3	3
Economic	3	3	2	1

Figure 9. 6-Sigma table for Kanban solution

By observing the 6-sigma table above, the scoring system is as follows:

5. Manual Kanban: 12 points
6. Bar-code Kanban: 17 points
7. RF Kanban: 21 points
8. Robotic Kanban: 20 points

So the best system for Hospital Clinic is the RFID Kanban, which is now referred to as Smart Kanban.

6. DETAILED ENGINEERING

To elaborate this logistics improvement strategy plan, various procedures have been carried through, following the Lean approach.

6.1. Product development

According to Lean, the first move is that of identifying the mudas. This identification process was achieved differently (with different tools) for the case of the general warehouse and the storage rooms.

6.1.1. Warehouse Lean analysis

We started off by using the Lean tools for identifying the mudas, the tools used were the Layout and the Value stream mapping (VSM), as they were the most relevant to make use of.

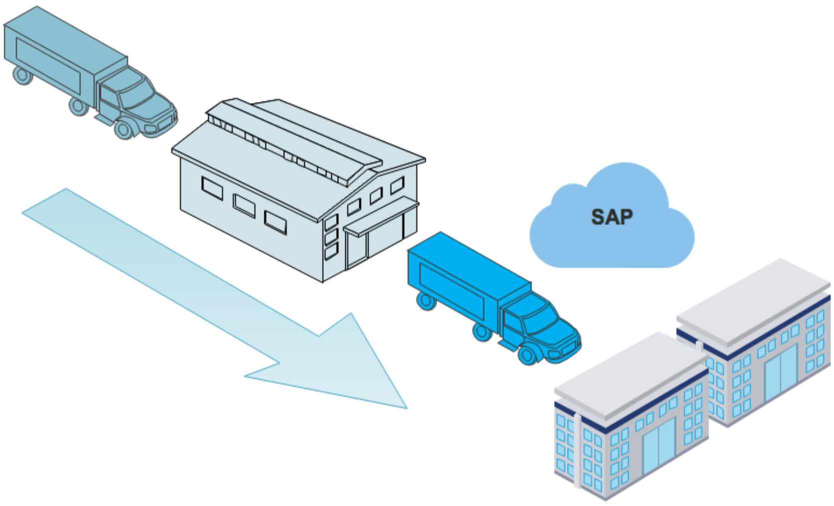


Figure 10. Warehouse Layout

The layout in figure 10, expresses how providers arrive to the warehouse with supply, that is stored in the warehouse as inventory and then delivered when ordered to hospital clinics entities.

The VSM was completed after describing each process with post-its stuck on a window, where we could change orders and add other processes with the help of the whole logistics team. Once all the processes had been described we were able to describe 6 processes with other sub processes.

The current warehouse situation described in a VSM can be observed in figure 11. We can divide the production control into two categories: entries and departures. The entries can be described in 3 processes: reception, work zone and placement, whereas the departures start off after a SAP order, followed by the picking and packing process and then the deliveries. The large blue and white striped arrow means that that one process leads to another, by the system of push, described in section 2.2. The timings for each process were noted down on an excel spreadsheet by observing all the processes from a nearby window, data was collected 10 times for each process and then the average was computed. The whole system in the warehouse lasts 30 hours, including the fact that it takes 24 hours between the SAP order and the picking and packing process. Each process also has sub processes that have also been represented by VSM, as observed bellow.

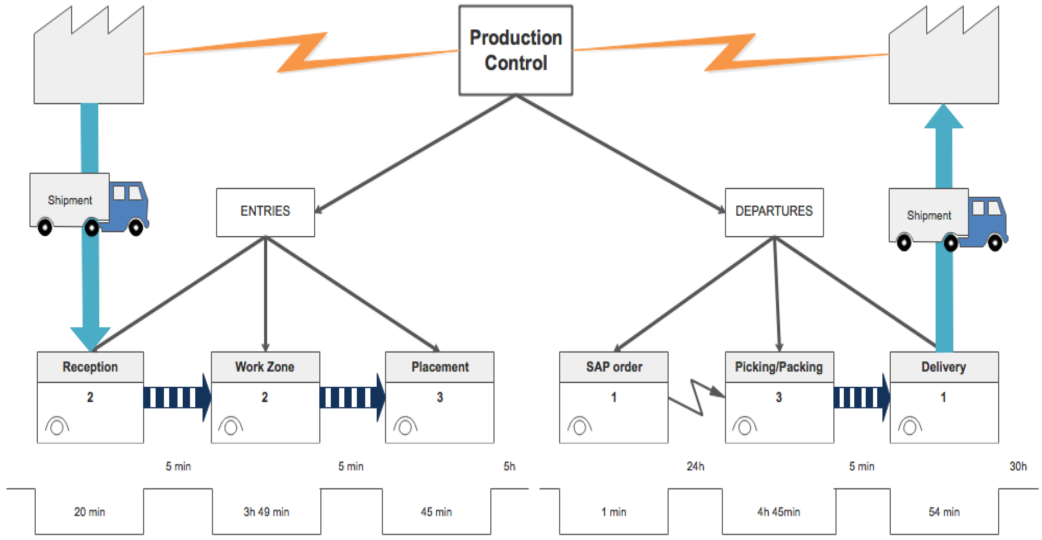


Figure 11. General warehouse VSM

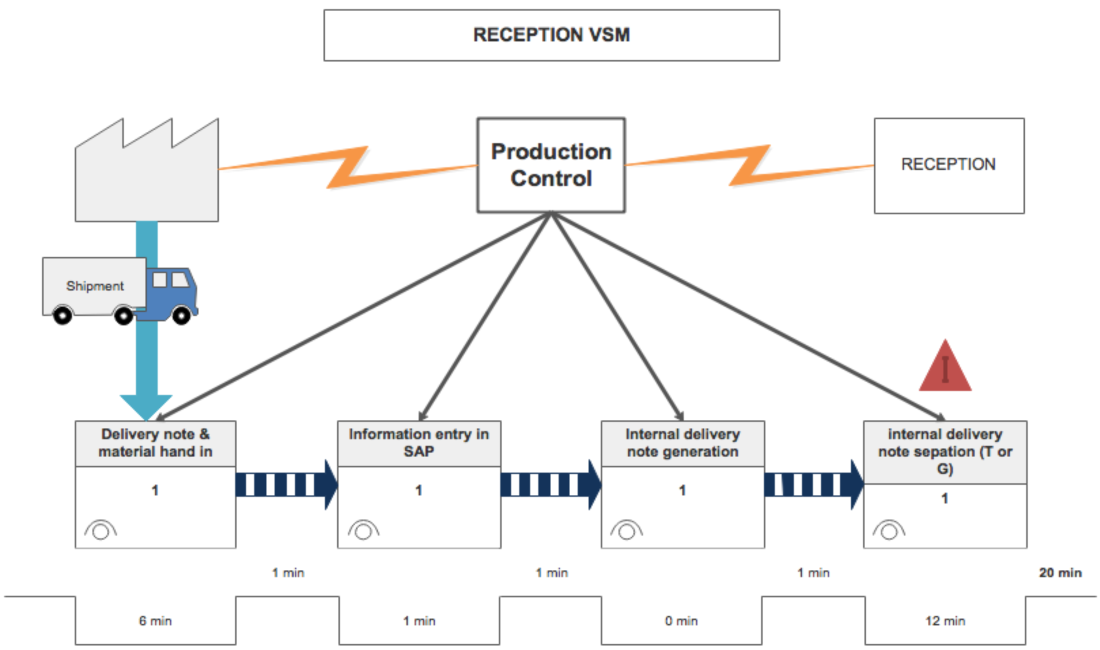


Figure 12. Reception VSM

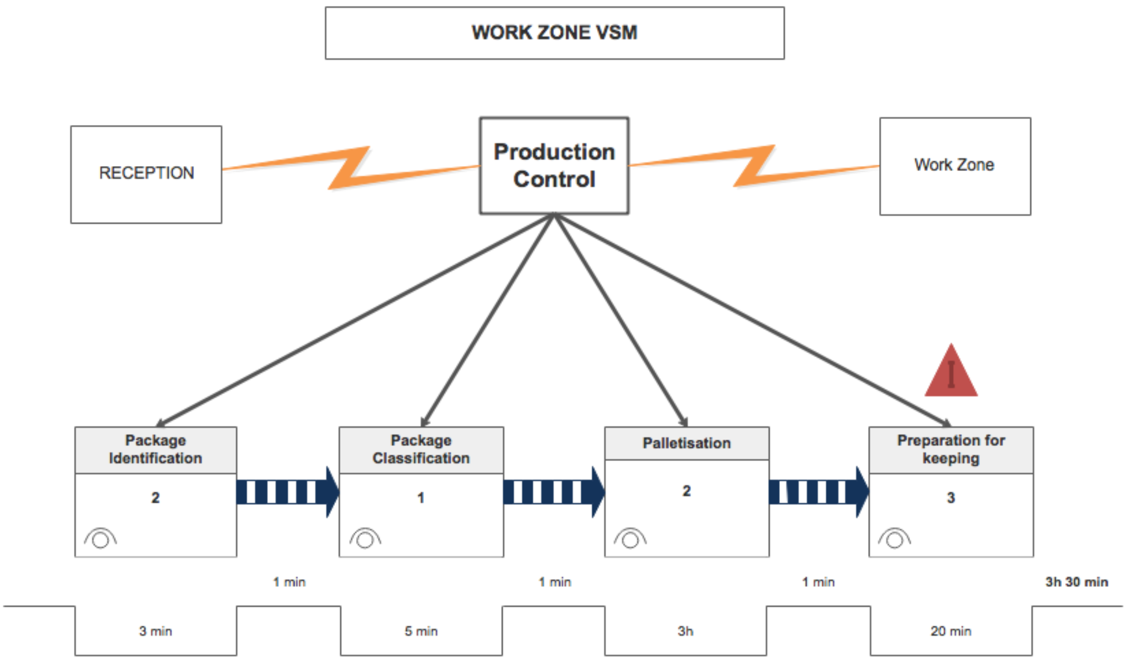


Figure 13. Work zone VSM

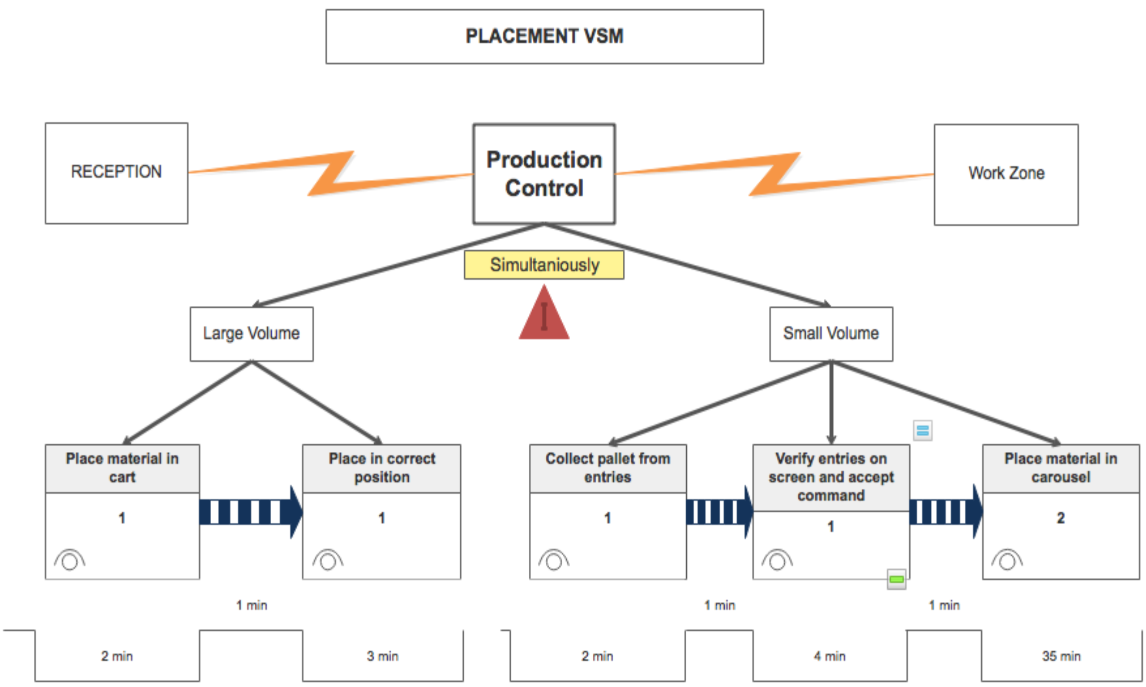


Figure 14. Placement of items VSM

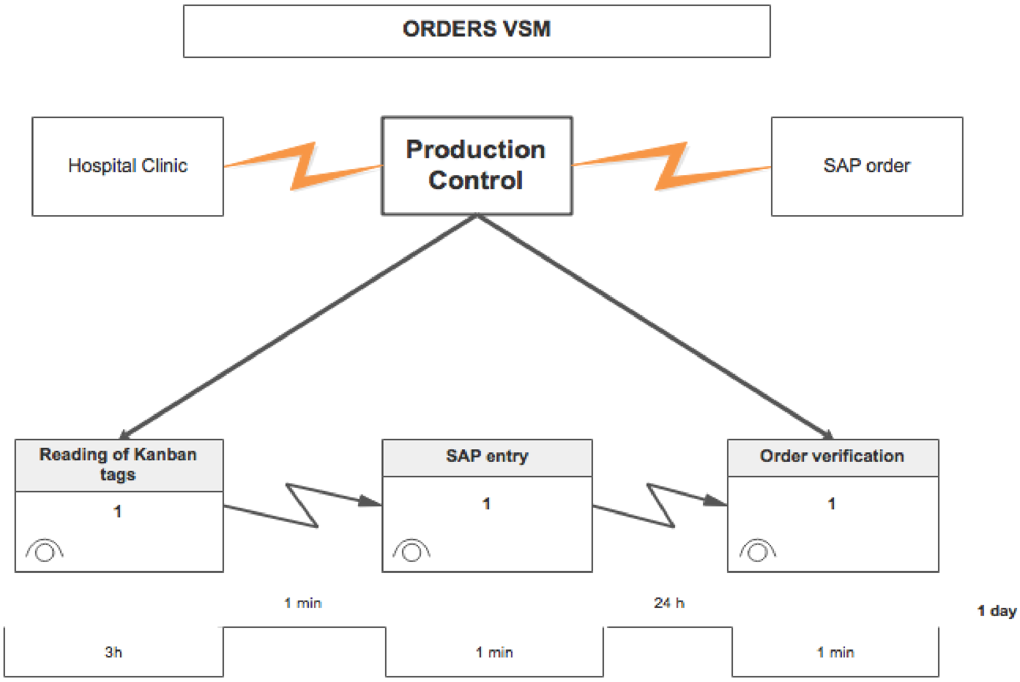


Figure 15. SAP orders VSM

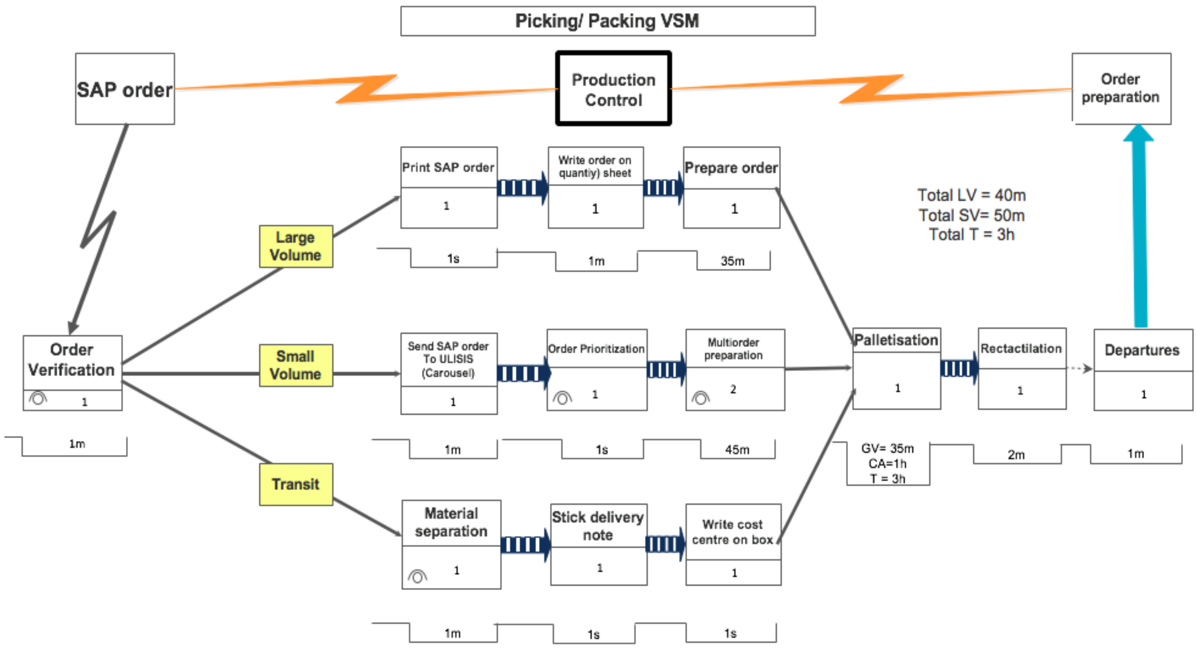


Figure 16. Picking/packing VSM

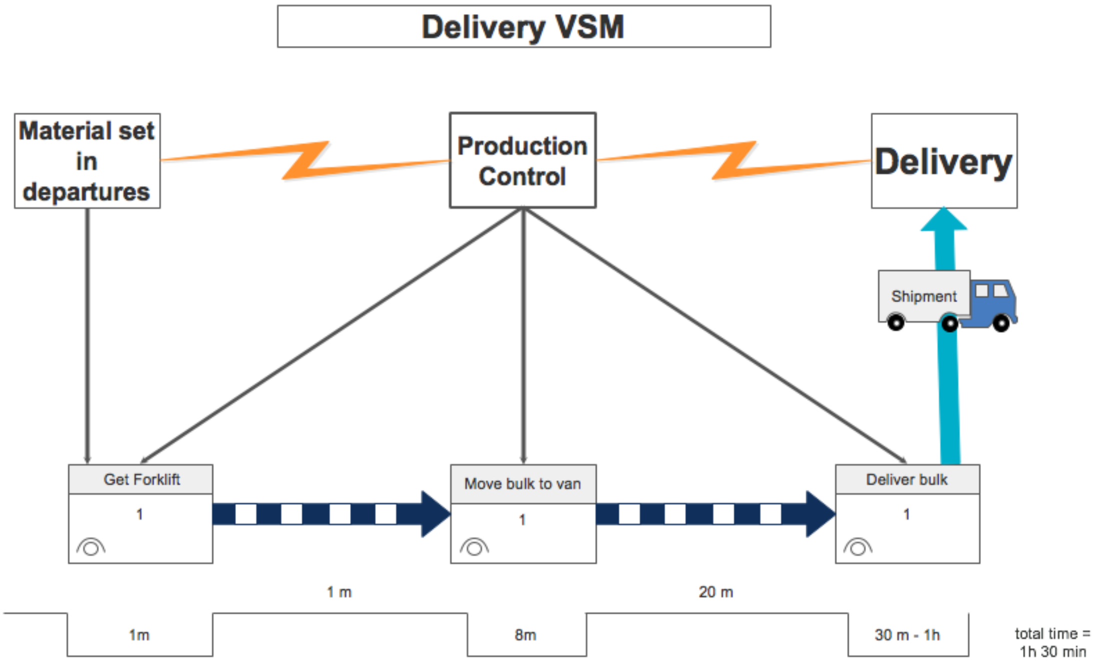


Figure 17. Delivery VSM

- **Reception.** The process of Reception can be observed in figure 12 and is done by 2 operators and is made up by the sub processes of handing in the delivery note and material packages, entering the delivery note information into the SAP software, generating internal delivery notes and finally classifying each delivery note, as it can be either transit material or large volume. The timings for each sub process can be seen in Annex 3. The whole reception process takes an average of 20 minutes, with the longest timings for the separation of internal notes into transit material or storage material.
- **Work Zone.** The VSM for the work zone seems simple to look at (Figure 13), but the process of package classification is not easy, figure 18 clearly explains the package separation procedure, where the operators have to firstly divide packages, boxes or whole pallets into stock or transit, then large/small volume and normal/refrigerated volume, consequently. The warehouse has 2 large refrigerators for storing cold items, as well as the fact that the cold items already come in *cool-boxes.*

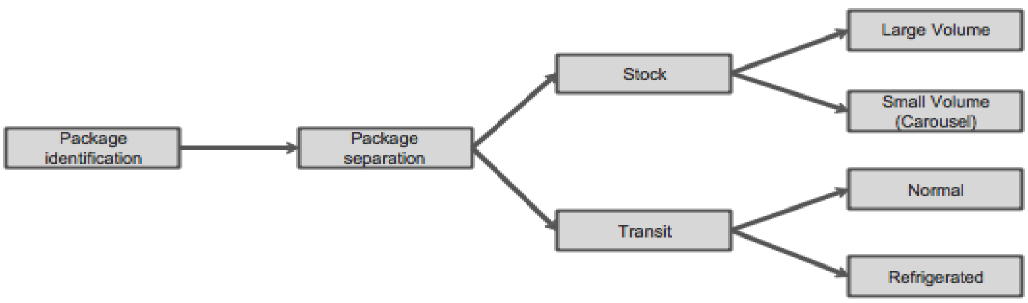


Figure 18. Package separation diagram

The longest timing is the palletisation, because the operators cannot place the material in its positions, until a pallet is completely full, which usually takes about 3 hours at its least, timings can be observed in annex 4 with a total timing of 3 hours and 50 minutes.

- **Placement.** This process simply consists in placing each material that has arrived into its correct position (Figure 14). The Large volume material is stored on pallets and the Small volume material is introduced into the carrousel. The longest sub process was found in entering the material into the carousel, it usually takes so long because a full small volume pallet contains far more items than a full large volume pallet, where the boxes just have to be positioned rather than individual items introduced into the carousel. The timing for large volume (Annex 5) takes an average of 4.6 minutes, whereas the timing for small volume placement (Annex 6), lasts an average of 40.6 minutes.
- **SAP order.** Orders are done from the hospital medical units, where the Kanban tags are read and the information is sent to the SAP software (Figure 15). Orders are picked and packed the day after the order has been placed. So the whole process takes about a day.
- **Picking Packing.** The VSM for the picking and packing process can be viewed in figure 16. After verifying an order, operators have to prepare the order. Yet again, operators pick and pack items from the small volume, large volume and transit areas. The longest timing is the carrousel picking/packing, which takes an average of 45 minutes (Annex 8). Again until the pallet is full, operators cannot move onto the next step. The timings for picking/packing for large volume (Annex 7) takes an average of 35 minutes. The timings for preparing transit volume (Annex 9) takes an average of 3.7 minutes.
- **Delivery.** The delivery process VSM can be observed in figure 17. Orders are prepared, then placed in the departure area, then an operator gets the forklift and places the pallets into the truck or van for it to be delivered to the hospital entities. Timings (Annex 11) lasted a total average of 53.7 minutes.

After describing all the processes, we looked at what takes up the most lead time and found several mudas with help of the VSM, where all timings and processes where shown. In table 5 we can observe the Mudas and Kaizen improvement proposals.

Process	**identified mudas**	**Kaizen improvement solutions**
Reception	Motion, delay and over processing.	Automate by including Bar code reader connected to SAP that parallel generates and prints internal delivery notes to be stuck onto packages for simple identification.
Work zone	Motion, delay and conveyance.	Include technology that classify, palletise and prepare automatically.
Placement	Motion, delay, conveyance and inventory.	Include technology that places material by reading a label with RF.
Ordering	delay and inventory	Improve Kanban system.
Picking/packing	Motion, delay, conveyance	Include technology that facilitates the picking/packing as well as improving the ergonomics, in order to gain higher productivity.

Delivery	Delay	By automating processes of above, there will be less delays in delivery.

Table 5. Lean Kaizen improvement chart

So by eliminating mudas and proposing Kaizen ideas, the improvement situation comes down to including automated machinery.

6.1.2. Storage room Lean analysis

The muda identification tool for the storage rooms was different to in the warehouse mainly because the rooms already use the Lean Kanban method, so the case was mainly about refining the Kanban technique, but to do so we still had to find its mudas. The tools used were value stream mapping again and 5S, followed by a thorough Kanban analysis and experience.

Interestingly, we are able to describe the Kanban process with a VSM (Figure 19). The map explains how there are two types of stock: the safety stock and the usage stock, both are supplied by the supplying processes that flows through the warehouse, ready for the user process.

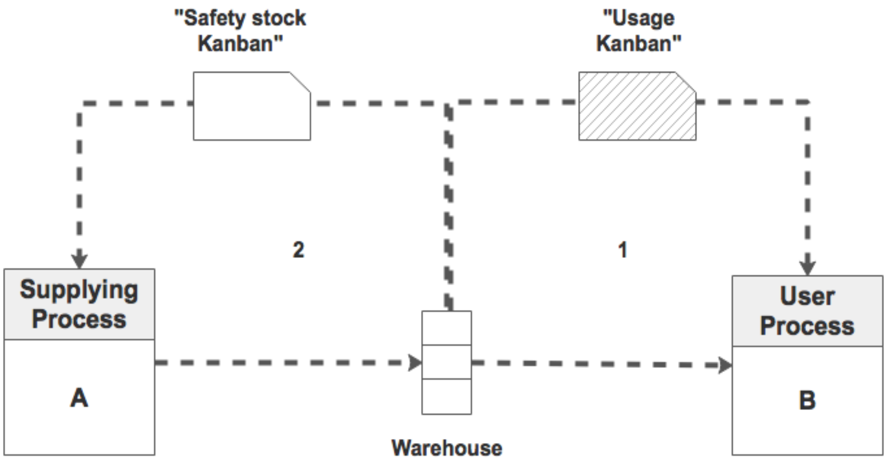


Figure 19. Kanban VSM

The timings of the process happen once a week, and twice a week for Intensive Care Units (ICU). Sometimes nurses forget to pin Kanban cards up, leading to delays in refilling compartments.

The 5-S method basically consisted in organizing the storage rooms, making it neat, tidy and clean. The first thing done was eliminating all unwanted material, which was indicated by the red tagging technique, where if unsure whether or not to throw out, a red sticker was stuck to the items. As the hospital possesses 66 medical units, we did not have time to apply this technique to all storage and control rooms. So the technique was applied only to the gynaecology unit in the maternity centre. With this technique we got rid of empty boxes, a chair, some medical devices that were occupying space and expired material.

We then did a Kanban analysis, in order to gain statistic proof of the malfunctioning of the system. This was accomplished by visiting 3 completely different storage rooms and counting the quantities of each material, to then compare this with the amount the Kanban tag displays. The list of material and quantities for each department was taken from the SAP software, the annotations of amounts were done on Excel, as for simple calculations like averages, etc. Whereas further statistic studies were done on Rstudio.

The analysed storage rooms were gynaecology in the maternity centre, haematology from the main hospital clinic and the cardiology unit also from the main hospital. Each unit had its own personal characteristics, which is a consequence of a deficient standardization. The data was taken the day before each departments material needed refilling, so some tags were pinned up as to command the refilling of items, the actual physical amount of material in each compartment (real quantities) was counted and noted down. All tables can be viewed in Annex: tables 12, 13 and 14.

It is important to state that materials could be either type D or U, D for double compartment or U for unit, which is the most confusing concept for nurses and operators to understand. The objective of the study was to prove the bad use of the Kanban double compartment. In table 6 we can view the number of supposed double compartments or unit compartments per unit.

	Cardiology unit	**Haematology unit**	**Gynaecology unit**
Total amount of items	233	150	154
Double compartment	233	114	117
Unit compartment	0	36	37

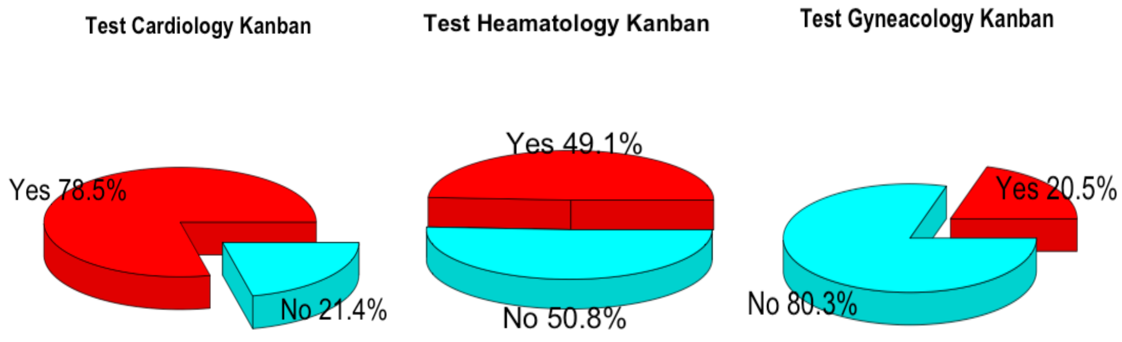
Table 6. quantity of material types

The first test consisted in using the interactive IF and AND commands in Excel for the double compartment material, as the counted quantity had to be larger or equal the theoretic quantity, but smaller or equal the double of the theoretic quantity, due to the two-bin Kanban rule (Expression 2):

$$\text{Theoretic quantity} <= \text{Real quantity} <= 2 \cdot \text{Theoretic quantity}$$

Expression 2. Double compartment quantities

If the command was true, then a "Yes" was added and if it was false a "No" was added. After this new test column was created, the whole table was opened in Rstudio and the package *Plotrix* was installed to make 3D pie charts (Annex 14).



183 yes, 50 No. 56 yes, 58 no. 24 yes, 94 no

Figure 20. Pie charts for Cardiology, Haematology and Gynaecology units, Kanban quantity obeyance.

We quickly concluded the grand differences between units, and that none of them were working correctly, with gynaecology being the most malfunctioning. Cardiology proved to be the best working, but then we noticed the room full of boxes with material stacked in a corner, this was the reason why they always had the correct quantities, because nurses would refill compartments with their own separate safety stock kept in bulk.

Identified mudas	Kaizen improvement solution
Delay	Better training scheme to explain Kanban to nurses properly.
Inventory	Automate using RFID to keep better track of inventory. Also, prohibit nurses from keeping stock in bulk.
Conveyance	Remove any equipment/devices that is not meant to be kept in storage room.
Motion	Use RFID Kanban with works real-time and avoid having logistics operator manually read bar codes.
Correctness	Training scheme to explain idea of Kanban quantities and double compartments.
Disconnects	Training scheme explaining the importance of Kanban, to avoid disconnects from appearing.

Table 7. Lean Kaizen improvement chart

As breifly explained above in table 7, the goal is to make sure the nurses and operators follow the Kanban double compartment method correctly, without overstocking, delays, etc. To do so the idea is to automate the storage rooms with RFID technology.

6.2. Experimental validation

In the case of the warehouse automation, there is no need to do any experimental validations, as the new technology is currently being used in many other warehouses and is semi-robotic. Hence, in the case of the Kanban system, we thought it useful to do a pilot practice test in one of the departments as to prove that the new Kanban application will work smoothly. The whole experiment has been done in the hospital Clinic's maternity institution, in the gynaecology unit, as its Kanban analysis proved the worst running.

6.2.1. Pilot Kanban test preparation

The main goal was to accomplish a successful test outcome without spending any capital, to prove that a newly improved Kanban system would work successfully in the future. Before adding bits to the systems, we took our time in organizing the rooms properly following the 5S tool and making the plan very visual. It is important to state that we kept a very close eye on everything to avoid any possible errors to do with what is described as the human factor, which if automated would be minimised.

We first obtained the list for the gynaecology department of all its material and details through SAP and followed the next steps:

<u>1. Print Kanban tags.</u> We printed out the tags with the list provided through SAP. We had a total of 136 codes.

<u>2. Colour tags fluorescent yellow and put cases on.</u> These yellow tags are now the Kanban *safety stock* tags.

Image 11. Kanban safety stock elaboration

<u>3. Organize compartments for each material.</u> Consisted having the *use* compartment with a white tag and the *safety stock* compartment with a fluorescent yellow tag. Here we found ourselves in the problem of finding out that some compartments were not double and that some compartments were not being used, so we had to make room for double compartments, which was not possible in some cases. We also found that in some cases the same items were found in the control room as well as in the storage room, so the organization step also consisted in organizing that disorder.

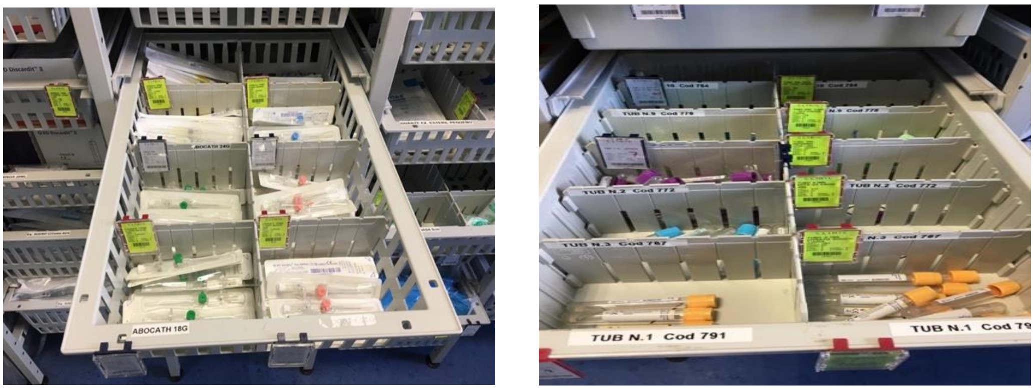


Image 12. Kanban compartment organization

<u>4. Training plan.</u> This was probably the most complex step, vital for everything to function properly. We explained how Kanban works to all nurses, assistants and operators. Emphasizing how the double compartment benefits them in many ways. The instructions for them were simple:

> A. Always take material from the white tag compartment. When material runs out from white tag compartment, hang white tag up.
>
> B. Only take material from the yellow tag compartment when the white tag compartment is empty.
>
> C. If and only if yellow tag compartment runs out, hang yellow tag up.

The objective is that yellow tags should never reach the point of having to be hung up, because they are *safety stock.* In this process of explanation, we made sure they fully understood how the Kanban process works and made them realize that they do not have to worry about running out of items if they follow the method properly.

We also had to explain the system to the replacing operator team and to the reading operator. As for the replacers it was simple:

> A. Just fill the compartments whose tags are hung up, whether it being use or safety stock.
>
> B. Once the compartments have been refilled, place tags on compartments.

As for the reading technician, we explained that they read as usual, except for when they see a yellow tag, which they have to send off as "Emergency replacement order", to be delivered as soon as possible. With RFID Kanban, the wireless technology would automatically warn SAP about the emergency in real time.

<u>5. Observation and control.</u> This step consisted in observing how nurses, assistants, reader technicians and replacers made use of the Kanban system and avoiding them from making any mistakes and constantly giving them positive feedback when done correctly.

6.2.2. Results

The pilot Kanban test turned out positive, as the results for the initial Kanban analysis in the gynaecology department and the new results completely turned around. This proves that a properly implemented Kanban method works successfully.

The bad use of the double compartment, where nurses and operators failed to understand the concept of the 2 bins, worked out positive as observed in figure 21, with 84% of the double compartments used correctly.

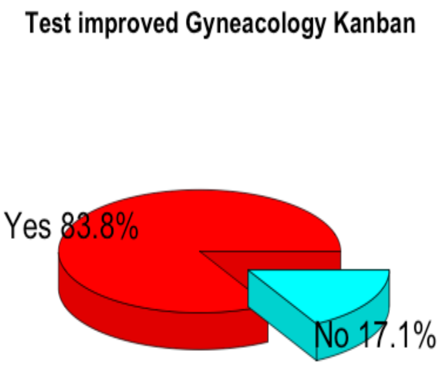


Figure 21. Kanban pilot test pie chart

We also computed the average of the amounts of material in the gynaecology unit (Table 8), and understood that the average of the quantity of material in this unit should be between 80.296 and 148.266667. The average for the previous Kanban analysis was of 37.22963, whereas the result of the pilot Kanban test was of 84.792526, which fulfils the criteria.

	Used double compartments	Full double compartments	Kanban analysis	Pilot Kanban test
Average of items	80.296	148.266667	37.22963	84.7925926

Table 8. Average of items chart

We then did a statistical paired t-test, where we compared the counted quantity of before and after implementing the pilot Kanban and obtained a rounded p-value of 0.01, which is smaller than the 0.05 criteria, meaning there are indeed significant differences between quantities.

We also looked at the cost-consumption data provided on the SAP software for the gynaecology unit for the years 2015, 2016 and 2017, for months February to May, and noticed that the consumption in the gynaecology units' storage room in May 2016 (after implementing the pilot plan) was of 778.25€, whereas the consumption in May 2017 dropped down to 707.43€, meaning a 9.1% saving.

	February	March	April	May
2015	611.79€	1,000.33€	705.91€	764.08€
2016	747.57€	913.55€	776.52€	778.25€
2017	648.07€	935.33€	861.77€	707.43€

Table 9. Gynaecology unit monthly medical material expenses

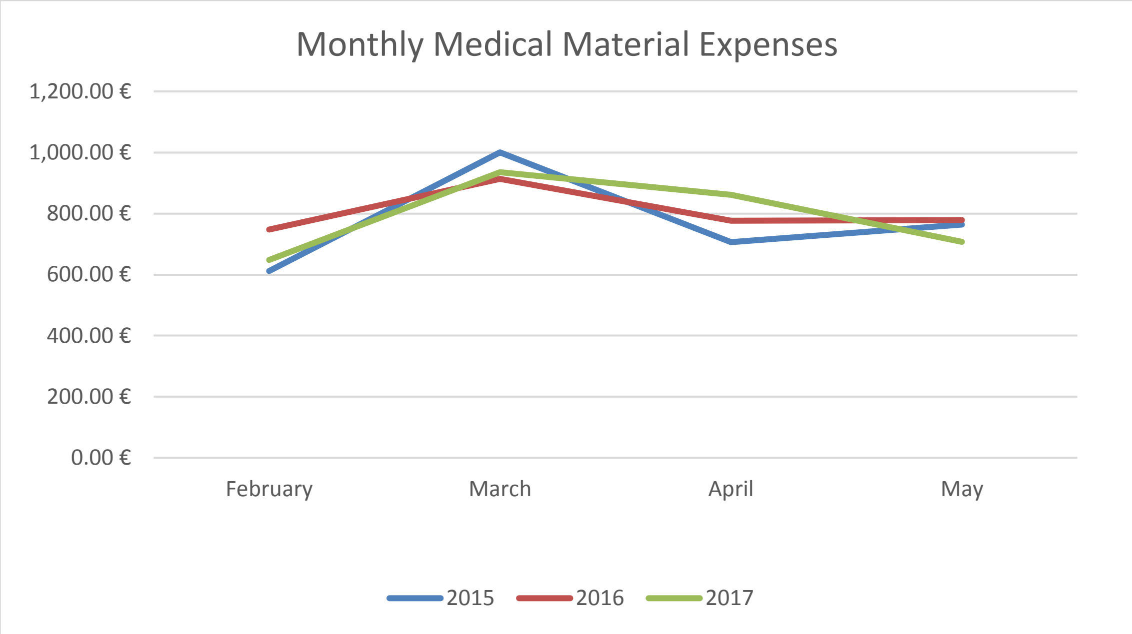


Figure 22. Gynaecology unit monthly medical expenses chart

During the month of Abril 2017, the consumption for the 66 medical units for medical material has been of 529,999.21€. If the 9.1% saving is applied to this figure, the total cost is of 481,769.3€, meaning a whopping 48,229.93€ is saved. This backs up the idea that a properly implemented Kanban increases efficiency and optimizes systems and that the implementation of the Smart Kanban that uses RF, will have a real time inventory control, which the system will benefit from and save up even more.

It is important to state that during the first month of the pilot test, costs did not double as in 2004 because as the storage room had such a stock overflow, we directly used that material for the double compartments.

6.3. Improvement plan put together

1. Warehouse automation

The new automatic warehouse will be made up of unit loads and mini loads, the chosen company is ULMA. Both machines work in the same manner. The automatic warehouse, as shown in the VSM below (Figure 23), is divided into two procedures:

1. Entries: Firstly, providers bring in the packages, boxes or bulk pallets into the warehouse reception, where delivery notes are handed in and read, to automatically generate and print an internal delivery note (which will either be a bar code or a QR code), which is stuck to the material and placed into the load. Then the load places the material in its correct place via radiofrequency, because each tray or pallet has a RFID tag with its antenna stuck to it.

2. Departures: It starts of with a SAP order, then there is an on-screen picking control, where the load brings the pallet or tray with material to the operator, to do the picking and packing. Then palletisation and rectactilation is done and ready to be delivered to the hospital.

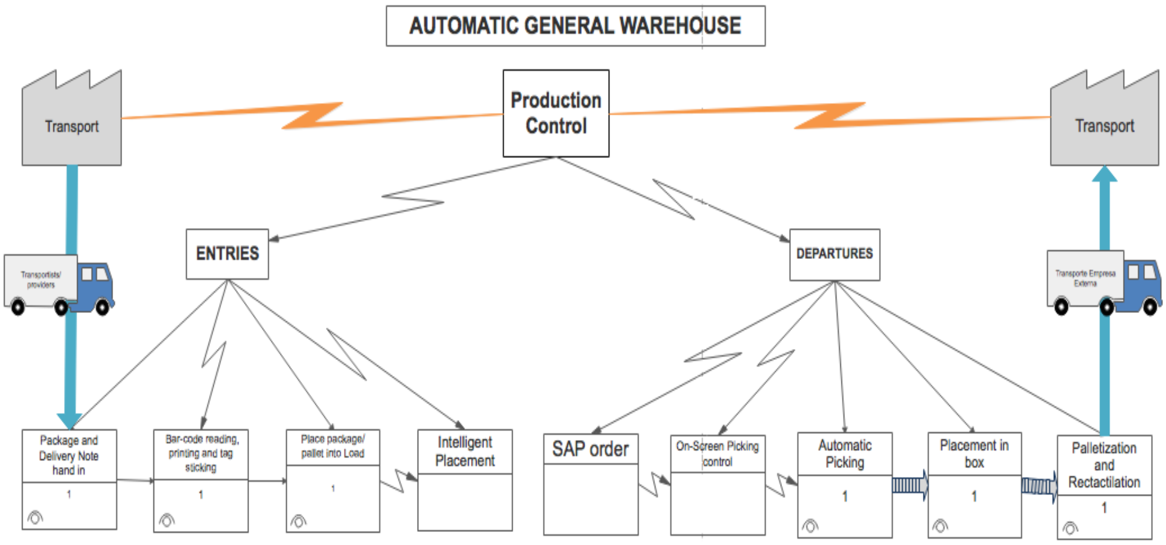


Figure 23. Automatic general warehouse VSM

The warehouse will be composed of 2 Unit-loads and 1 Mini-load and will therefore benefit from:

- ✓ Passing from storing 260 pallets to 400 with the Unit-load system
- ✓ Optimizing space with the load systems (No more air filled space)
- ✓ Storing transit material in the Mini-load system
- ✓ Storing pharmacy Serums, with controlled temperatures in another Unit-load (46 pallets)
- ✓ Paperless warehouse control (Everything will be digital)
- ✓ More labour safety
- ✓ Productivity increase
- ✓ More accuracy
- ✓ Significant decrease in the human factor error rate
- ✓ Silent machinery
- ✓ Ergonomic improvement for operators

As so much space can be optimized by including a mini load for small volume and a unit load for large volume, an extra unit load will be included to store refrigerated material, as well as pharmaceutical serums, which occupy a lot of space in the pharmaceutical storage room in hospital Clinic. The floor plan can be observed in figure 24 with the unit loads and the mini load.

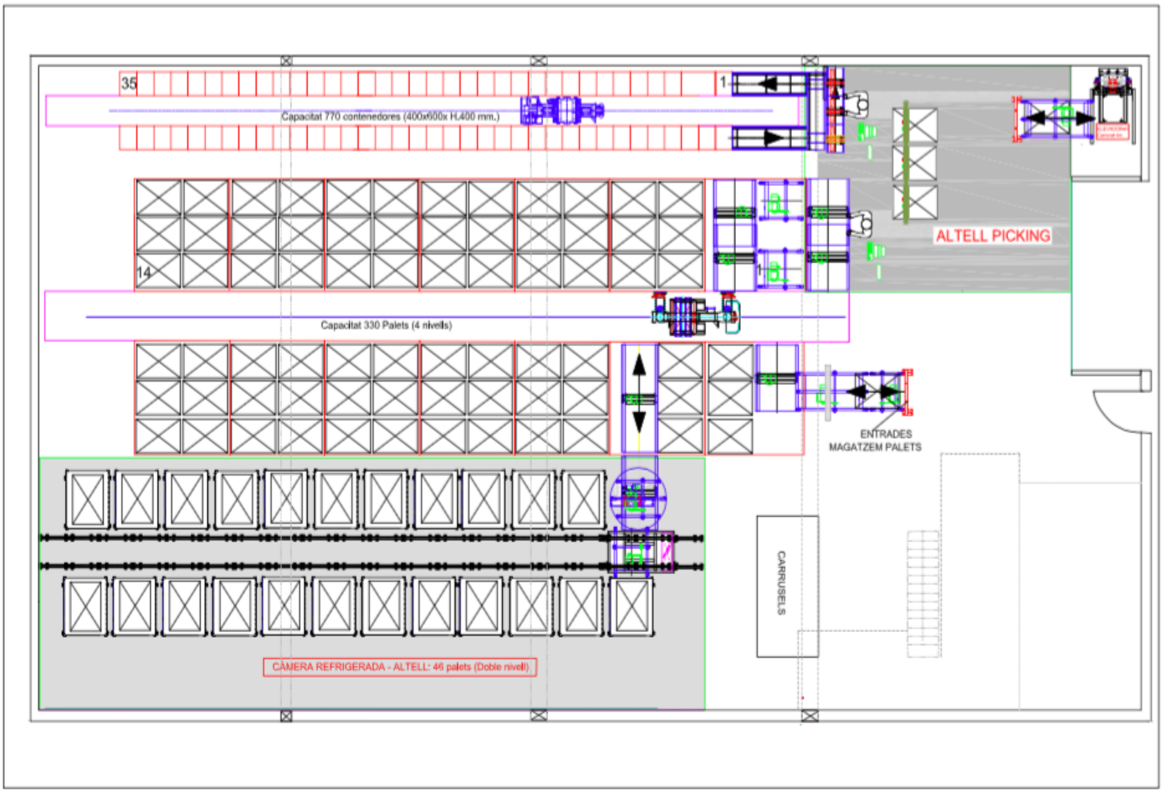


Figure 24. Floor plan for automatic warehouse. from top to bottom: Mini-load, Unit-load and refrigerated unit-load

2. Storage room automation

The implementation of RF in the medical units, will benefit the Kanban system in the following ways:

- ✓ Real-time control on stock and orders
- ✓ Elimination of tag manual reading
- ✓ Cost savings
- ✓ Configurable alerts and notices
- ✓ Less stress and hassle for nurses
- ✓ Simple and easy to use
- ✓ Easier way of following Kanban properly
- ✓ Automatic "emergency" ordering

The medical units will be composed of 2 RF reading booths and two types of cards per material, an orange one for safety stock and a white one for ordinary use, the cards will have a RF chip inside them, that once in contact with the reader, the command will directly flow into the SAP software. If the reader detects an orange card, SAP will receive the emergency order command. The chosen company is Palex.

Figure 24. Palex devices. From left to right: Palex booth and Kanban RFID tags

7. TECHNICAL AND ECONOMICAL FEASIBILITY

7.1. Technical aspects

The project has been developed in the Logistics Department in Hospital Clinic and therefore all the equipment and facilities have been obtained from there.

The needed facilities have been:

- Hospital logistics office
- Main warehouse
- Medical unit storage rooms
- Transit area

The programmes used have been:

- SAP software
- Microsoft Excel
- Rstudio
- Edraw

7.2. Economical aspects

7.2.1. Cost and funding

The proposed scheme has yet to be confirmed and then authorised by a competitive dialogue, to be financed by the *Generalitat de Catalunya,* according to articles 179 and the *Texto Redundido de la Ley de Contratos del Sector Público* (TRPLCSP), the total budget is of 1,750,000€.

The company ULMA has proposed an economical offer, that includes the mini-load, the unit-loads, a VTD/UHS double level system and an elevator/descender, for 993,000€, without including TAX.

ULMA equipment	**Price (€)**
Unit-Load automatic satellite system for pallets	395,000€
Mini-Load automatic system for containers	385,000€
VTD/UHS double level system	145,000€
Elevator/Descender attic + attic	68,000€
Total	993,000€

Table 10. ULMA equipment prices

These prices are approximated without the inclusion of tax, pallets, handling units (wheelbarrows, transpallets, etc), workforce, Ethernet network installation (220 V network), fire prevention system and other elements to be further discussed. The budget for the warehouse automation is of 1,500,000€.

As for the implementation of RFID in the Kanban management of medical units, NICUs and ORs. The chosen company is Palex, with their Smart Kanban system, where a RF booth costs 1200€; two booths would be needed per medical unit (1 booth for control room and 1 booth for storage rooms), meaning that each unit costs 2,400€. Again, there are a total of 66 units.

Palex equipment	**Price (€)**
132 booths	158,400€
IT softwares	5,000€
RFID Kanban tags	2,000€
Total	165,400€

Table 11. Pallex equipment prices.

These prices, again do not include tax, Ethernet installation, workforce and other elements

7.2.3. Amortization feasibility

The warehouse automation plan will be amortised in a total of 2 years whereas the Kanban automation will be amortized in 4 months.

- Automated warehouse amortization

The general warehouse currently has 9 members of staff plus 6 operators from the external company. With the warehouse automated, the external company and substitutes will be removed completely and the warehouse will go from needing 9 operators to only 4. The remaining 5, will be relocated to hospital Clinic to help out in the transit area. The amortization study was done by the logistics team and they computed 2 years of amortization.

- Automated Kanban amortization.

The automated Kanban system, will quickly be resolved as the total cost was of 165,400€, and with an improved Kanban reducing 9.1% in expenses, meaning around 48,229.93€ is saved in a month. This system can be amortized within 4 months.

7.3. SWOT analysis

A Strength, weakness, opportunities, threats (SWOT) analysis has been elaborated for the whole Logistics improvement strategy (Figure 25).

STRENGTHS	WEAKNESSES
- Radiofrequency - Real time control - Better stock control - cost-effective - Professional comfort - higher productivity	- No time to analyse each medical unit - Space limitations - Human error factor
OPPORTUNITIES	**THREATS**
- Logistics automation in hospital environments growing - Lean approach becoming popular in Europe - More necessity of real time data acquisition	- Competitive dialogue pressure - Sanitary budget cuts - Recession in Spain

Figure 25. SWOT analysis on logistics improvement strategy plan

8. FORECAST SCHEDULE

8.1. Task definitions and times

The tasks along with the corresponding task-times have been defined below:

0. Bibliography and research. From the 1st of November 2016 to the 1st of June 2017. The project research and bibliography was done parallel respect to the rest of the tasks. Research includes properly understanding the theory behind Lean, Kanban in particular, programmes and software used, warehousing machinery and other aspects.

1. Logistics department training. From the 6th of February to the 15th of February.

> **1.1. Logistics understanding behind storage rooms.** During the first week, it was important to grasp a good understanding of how the logistic department works and what they do. The first week basically consisted in having a tour around the main transit area and storage rooms.
>
> **1.2. Logistics understanding behind the warehouse.** During the second week, it was important to get a better vision of how the system works by visiting the warehouse in *Cornellà.* The first 2 days purely consisted in being shown around the warehouse and understanding each process, the rest of the week consisted in understanding the ULISES programme used for the carousel.

2. Warehouse analysis. From the 25th February to the 31st March.

> The warehouse analysis took place in 4 weeks. The objective was to fully understand each process, this implied directly participating in each process, to then be able to elaborate the Lean VSMs for each process. I also had to collect data on the timings for each process. My engineering point of view was very useful for finding many ideas for improvement.
>
> **2.1. Reception.** The first understanding was the reception task, which consisted in receiving delivery notes, stamping them, handing them back and introducing the information into SAP software. It was a very simple task, but the human error factor was big there as the receptionists had to manually type in each material code (20 characters) into the programme.
>
> **2.2. Work zone.** Then the understanding was based on helping out in the work zone, which consisted in identifying packages or pallets, sticking its corresponding internal delivery note onto it and stacking boxes on pallets for each category. This was a very exhausting process.
>
> **2.3. Placement.** The process of placement was rather simple, it consisted in positioning each box into its correct position. This information was found on the internal delivery note. The boxes could either be positioned into aisle A, B or C. The process was rather tiring as a lot of physical effort was required.

2.4. Picking-packing. The picking-packing process was very important to play a part in as to understand the functionality of the carrousel. I did the process in the carrousel and also in the large volume. It is a simple procedure, though the human factor is always present, especially when doing a process so quickly, as time is priceless The process was also very tiring.

2.5. VSM analysis. Consisted in describing each process, this was done by sticking post-its onto a window indicating each step and thinking of possible improvements for each process. The point was to create VSMs in order to identify the mudas.

2.5. Time calculation. Durations for each process and sub process were timed and noted down, to later make the averages to add the timings onto the VSM as to complete them and find mudas.

3. Kanban analysis. From the 3rd of April to the 1st of May.

3.1. Kanban reading. Consisted in going into the storage rooms with the logistics operator, who would read all the pinned up Kanban tags with the barcode reader connected to the SAP software. The point was to understand how Kanban works and comprehend how the nurses follow the Kanban system, again looking for mudas. I also went with the repositioning operators to understand how the items are refilled.

3.2. Kanban comparative study. Consisted in doing a comparative study on the material quantities for the Cardiology, Gynaecology and Haematology units. The tasks consisted in counting the amounts of each item and typing them into Excel, for them to be compared with the set amounts stated on the Kanban tags. Lots of conclusions were made after doing this comparative study.

3.3. Rotation and location analysis. Consisted in seeing whether or not repositions done once a week was enough for each department and also seeing if the storage rooms were located in the right spot, basically to spot any other possible improvements.

3.4. Pilot Kanban test preparation. The pilot Kanban test, was done in the gynaecology unit in the maternity centre, as it was the unit with the worst Kanban results after the study done the week before. The task consisted in preparing the tags for the experiment and organizing the unit.

3.5. Pilot Kanban results. Consisted in counting the material quantities in the gynaecology unit and then comparing them to the results from the pilot test. During that week a heavy SAP economics understanding of the costs department was necessary. This task was essential to prove that a properly implemented Kanban system works efficiently.

4. Automation plan. From the 24th of April to the 8th of May.

4.1 Warehouse automation. Consisted in understanding the high tech behind warehouse automation, knowing the used machinery in other warehouses used for hospital material.

Here lots of research was done on carousels, rotators, load systems and I was fascinated by the new amazon robots.

4.2. Storage room automation. I was invited to several meetings with sales companys such as Palex and *Griffols*, which helped choose the right Kanban automated system.

VSMs were put together and the plan was put together with the help of the team.

6. Redaction and corrections. from 1st of April to 12th June.

The project was shown to the coordinators and to the tutor, who revised and corrected it.

8.2. GANTT diagram

A Gantt diagram has been created as shown in figure 26, with its legend in table 12.

Gantt legend			
Task A	Bibliographic research	**Task D**	Lean Kanban analysis
Task B	Logistics department training	**Task E**	Plan put together
Task C	Lean warehouse analysis	**Task F**	Redactions and corrections

Table 12.Gantt legend with task definitions

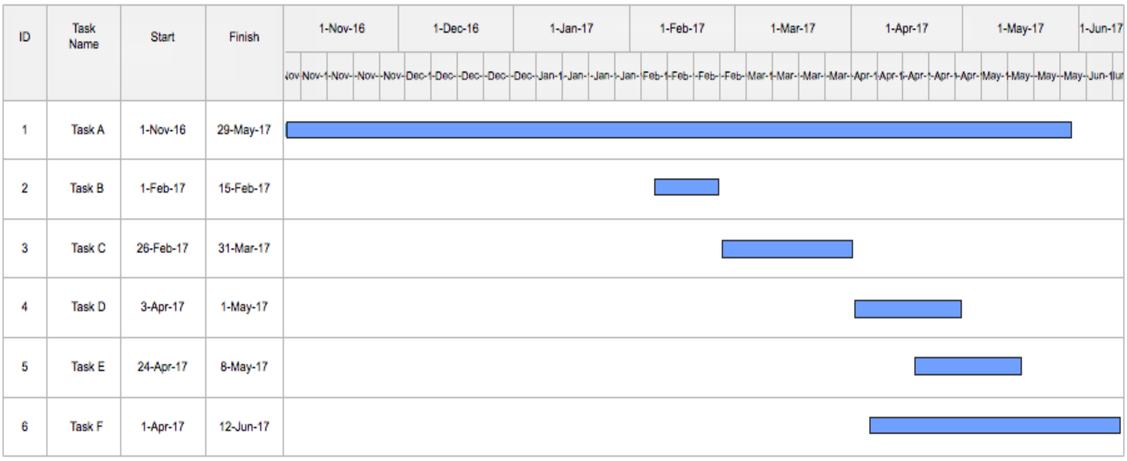


Figure 26. Gantt diagram

9. CONCLUSIONS

The objective of the project was to design a logistics improvement strategy for medical units following the Lean methodology by automating Hospital Clinics General Warehouse and the 66 storage and control rooms. The scheme consisted in using load system machinery for the warehouse and Smart Kanban RFID systems for the storage rooms, as to gain more efficiency by eliminating various processes, improving ergonomics, increasing productivity, optimizing space, digitalizing and other relevant aspects.

The popular Lean approach was followed for the plan elaboration, which gave the project a visual understanding of all procedures and tools to find processes or aspects to eliminate, identified as mudas and ways to improve the whole systems output. The implementation of the Lean methodology has been growing throughout Europe in many hospital environments. The Lean thinking mentality, which bases itself on the need of constant improvement, perfectly fits into the ideology behind the medical logistics field.

A pilot improvement Kanban test was done in the gynaecology unit, where RFID Kanban was simulated. Each material had a double compartment: one for use, with a white Kanban tag and one for safety stock, with a yellow Kanban tag. The objective was to train the nurses and operators to understand the Kanban rules properly in a very visual manner, so that then the quantities would be the proper ones, to then avoid stock overflow. The RFID was simulated, as the logistics team were constantly supervising and checking if any yellow tags were pinned, in order to set an emergency order. By the end of the month, the Kanban pilot test results turned out positive, with a saving of 9.1%, which if applied to the monthly cost of all the units, saved 48,229.93€, meaning the technology can be amortized in 3 to 4 months or less. Hence, we are able to firmly conclude that nurses and operators seem to have no idea about Kanban, so a Kanban training is required to avoid a negative practice.

Additionally, we can state the necessity of biomedical engineers in health logistics due to the lack of communication between departments, as well as to provide a critical health engineering point of view. Also, there is a noticeable absence of standardization in medical units, as each unit portrays different characteristics and functions differently, which also comes down to the poor communication between departments.

The final project also pays strong attention to decreasing human error rates by automating systems and increasing ergonomics, as to follow the trend of professional comfort, which is also a Lean manufacturing technique, because it helps produce the maximum work output without physically harming the workers.

As for further discussion, it is relevant to reaffirm the complexity behind hospital logistics and the fact that it is a constant challenge to accomplish the hospital requirements and of course the constant pressure of not having delays, human errors, etc. as unfortunately, a simple error could come down to a point of life or death. The whole project design has been a very multifaceted procedure due to the prerequisite of first understanding how all the systems work, from the different departments involved, software, machinery, Lean concepts, companies involved, finance and other matters.

Moreover, it is important to acknowledge the hefty amount of capital that goes into hospital logistics, which directly depends on the *Generalitat of Catalunya*, meaning politics and country economy is straightforwardly involved, this therefore sustents the need of creating awareness of the whole situation.

Lastly, to conclude that this final degree project on health improvement is very relevant to hospital clinic and if studied and approved by the competitive dialogue and put into practice, the modifications should turn out very positive, causing a chain reaction on the rest of the medical departments, making this project be of a major responsibility.

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