

Strengthening a public Hospital's internal Logistics system through Lean and optimization techniques

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Abstract

A Hospital is a complex system that has a proper performance when all the subsystems that are part of it work synchronously with the same goal: to provide the patient with the most efficient healthcare. What sometimes goes under the radar of the common user is how greatly operations within a Hospital are dependent on a strong internal Logistics system and that materials are available to health professionals in the right amount at the right time.

In this respect, continuous improvement projects to improve internal Logistics in a Hospital are not a novelty to the literature, nor the application of mathematical optimization models to the routing of internal Logistics. Nevertheless, the integrated application of both these methodologies has space for exploitation.

This dissertation aims at demonstrating an implementation of Lean methodologies to develop the teams and internal operations, based on a real application in the Provisioning and the Pharmacy team of a portuguese Public Hospital. Furthermore, it demonstrates how optimization models can help design the supply route of clinical consumables and medication minimizing waste of transportation, enhancing how intuitive and quick to implement Lean tools can go hand in hand with sophisticated mathematical models, such as Linear Programming and metaheuristics.

Regardless of the deductive method followed throughout this dissertation and being an employment of already known tools, the results are promising for future applications in other healthcare providers. Although several Lean projects in healthcare are already reported, the fact that it was born in the automotive sector and that the beginning of the transposing for the Healthcare sector is relatively recent implies that there is a transition that has yet to be fully completed.

Keywords: Lean, Internal Logistics, *mizusumashi*, Linear Programming, Lean Healthcare, Optimization

Resumo

Um Hospital é um sistema complexo que apresenta bons resultados quando todos os subsistemas que dele fazem parte trabalham de forma síncrona para o mesmo objetivo: proporcionar ao paciente os cuidados de saúde mais eficientes. O que por vezes passa despercebido ao utilizador comum é o quão dependentes as operações de um Hospital estão de um sistema de Logística interna forte, e da disponibilidade de materiais na quantidade certa à hora certa.

Efetivamente, projetos de melhoria contínua com vista à melhoria da Logística interna de um Hospital não são uma novidade para a Literatura, bem como a aplicação de modelos matemáticos de otimização para o roteamento da Logística interna. No entanto, a aplicação integrada destas metodologias deixa espaço por explorar.

Esta dissertação tem como propósito demonstrar a implementação de metodologias Lean para desenvolver equipas e operações internas, baseado num caso real num Hospital público português. Para além disso, demonstra como modelos de otimização podem ajudar a desenhar a rota de abastecimento de material de consumo clínico e medicação minimizando o desperdício incorrido em transportes, realçando como ferramentas intuitivas e fáceis de implementar podem ser implementadas em conjunto com modelos matemáticos sofisticados, como Programação Linear ou metaheurísticas.

Independentemente do método dedutivo que foi seguido nesta dissertação, e consistindo na aplicação de ferramentas já conhecidas, os resultados são promissores para futuras aplicações a outros prestadores de cuidados de saúde. Apesar de vários projetos Lean na saúde estarem já documentados na Literatura, o facto de a filosofia ter nascido no setor automóvel e de o início da transposição para o setor da saúde ser relativamente recente, implica que existe uma transição que ainda deve ser completada.

Palavras-chave: Lean, Logística interna, *mizusumashi*, Programação Linear, Cuidados de saúde Lean, Otimização

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"Life is a journey. When we stop, things don't go right."

Pope Francis

Contents

1	Introduction	1
1.1	Context	1
1.2	Problem Statement and Goals	2
1.3	Research Questions and Methodology	3
1.4	Document Structure	4
2	Theoretical framework	5
2.1	Lean in Healthcare	5
2.2	Kaizen Business System	6
2.2.1	Daily Kaizen	7
2.2.2	5S	8
2.2.3	Value Stream Mapping	8
2.2.4	Total Flow Management	10
2.3	Optimization	12
2.3.1	Exact Optimization methods	12
2.3.2	Approximate Optimization methods	13
3	Pharmacy improvement opportunities	14
3.1	Current Situation Mapping	14
3.2	Solution principles	17
3.2.1	Supermarket implementation	18
3.2.2	Handling unit	18
3.2.3	New layout	19
3.2.4	Standard reception and storage of material	20
3.2.5	Daily Kaizen for basic stability	22
4	Provisioning improvement opportunities	25
4.1	Current Situation Mapping	25
4.2	Solution principles	28
4.2.1	Periodical review of the Reorder Points for each reference	28
4.2.2	ABC/XYZ analysis for warehouse optimization	29
4.2.3	Handling unit sent to the Service, instead of the extensive count of products	30
4.2.4	Multi-order picking and other improvements	30
4.2.5	Daily Kaizen for basic stability	31
4.2.6	5S in the warehouse of each service	33

5	Supply system improvement opportunities	34
5.1	Current Situation Mapping	34
5.2	Solution Principles	35
5.3	Optimization Model	36
5.3.1	Exact Methods	36
5.3.2	Approximate Methods	38
6	Results	43
6.1	Multi-order picking	43
6.2	Pharmacy and Provision flow integration	43
6.3	Other results	45
7	Conclusions and future work	46
7.1	Conclusions	46
7.2	Further developments	47
7.3	The long-distant future of Hospital internal Logistics	49
A	Scheduling of reception and storage	55
B	KPIs of the Production Daily Kaizen board	56
C	Periodical review of the Reorder Points for each reference	58
D	File for time study of the Supply System	59
E	File for determining the best route using Linear Programming	60
F	Results of the 5S Campaign in the Obstetrics service	61
G	<i>Mizusumashi</i> route using approximate methods	63

Acronyms and Symbols

KI	Kazen Institute
HSOL	Hospital da Senhora da Oliveira
SNS	Sistema Nacional de Saúde (Portuguese Healthcare System)
KPI	Key Performance Indicator
VSM	Value Stream Map/Mapping
ROP	Reorder Point
LP	Linear Programming
SS	Safety Stock
CVRP	Capacitated Vehicle Routing Problem
GHAF	<i>Gestão Hospital Armazém e Farmácia</i> / Hospital Management of Warehouse and Pharmacy

List of Figures

2.1	Value Stream Mapping sequence. Adapted from Rother and Shook (2003)	9
2.2	Lean Production Pull System. Adapted from Chase et al. (2018)	10
2.3	Model of a hospital supply chain. Adapted from Volland et al. (2017)	12
3.1	Traditional Flow Mapping	15
3.2	Muda/VA Analysis	15
3.3	Current Layout of the Pharmacy	16
3.4	Process Mapping of the Reception of the material	17
3.5	New layout of the Pharmacy	19
3.6	Storage routes	20
3.7	Storage cars	20
3.8	Storage standard	21
3.9	Storage kamishibai	22
3.10	Template of the Traditional team Daily Kaizen Board	23
3.11	Production waste in monetary terms - Dashboard	24
4.1	Supermarket Flow	26
4.2	Service Level and Number of Stock Outs in 2020	26
4.3	<i>Muda/VA</i> Analysis for the Provisioning	27
4.4	Spaghetti Diagram of the picking for two different services	27
4.5	Relative location of the products according to rotation and consumption pattern	30
4.6	Internal Order Kanban	31
4.7	Picking - Current State and Future State	32
4.8	Picking car design	32
4.9	Picking car design with measures	32
4.10	Daily Kaizen Board of the Provisioning team	33
5.1	<i>Muda/VA</i> Analysis of the Supply System	35
5.2	Dimension of the boxes for Pharmacy and Provisioning	36
5.3	Dimensions of the transportation cars	36
6.1	Multi-order picking results	44
6.2	Linear Programming results	44
6.3	Comparison of results between exact and approximate methods	45
6.4	Graph of Linear Programming results	45
7.1	Future Internal Logistic system	48
7.2	Items by location to ease the arranging of materials	49
7.3	Hospital AGV	50

7.4	Hospital AGV	50
A.1	Standard scheduling of reception and storage	55
B.1	Used capacity of Production	56
B.2	Daily tasks fulfilled	57
B.3	Schedules fulfilled	57
C.1	Excel file for reviewing the ROP for each reference	58
D.1	Excel file for registering the time of the supply of Provisioning and Pharmacy for each service of the Hospital	59
E.1	Solver dialog box for the Linear Programming	60
F.1	Results of the 5S campaign in Obstetrics - delimiting space	61
F.2	Results of the 5S campaign in Obstetrics - Unload zone	62
G.1	Results of Linear Programming compared with 20 iterations of the Constructive Heuristic	63
G.2	Example of a Python route output	64

List of Tables

2.1	The Seven Types of Waste (adapted from Graban (2012))	6
2.2	Pull-flow in the internal logistics - adapted from Coimbra (2013)	11

Chapter 1

Introduction

The present dissertation aims to scrutinize and highlight the benefits of Lean practices and methodologies applied to the Healthcare sector - namely, applied to Hospitals' support services, such as Purchasing, Logistics and Pharmacy. The work was developed in Hospital da Senhora da Oliveira in Guimarães, Portugal.

Although Lean was a concept born in the automotive sector, it has proven to be an efficient improvement tool in many other sectors. Kaizen Institute Consulting Group is, worldwide, the most renowned responsible for designing and applying these methodologies in a handful of other companies, regardless of the sector or the country they belong to.

1.1 Context

Improvement projects are not a novelty in the Healthcare sector. However, in Portugal, the pressing need of improving the National Healthcare System has only been formalized in 2016 thanks to the XXI Constitutional Government, that through the dispatch in *Diário da República n.º4/2016, Série II de 2016-01-07* appoints the National Coordinator for the Reform of the National Health Service (SNS) in the area of Primary Health Care, that among other functions is responsible for implementing changes in the hospitals' network, particularly those that "promote a superior performance in quality and sustainability of the hospitals, involving the professional's development and the improvement of the patient's experience" (Alves et al., 2017). This report describes the top twenty improvement projects in Portugal, classified according to the summary of the projects, benefits for the patients, benefits for the hospital, investment, exploitation costs, performance indicators and replicability. Five domains, considered as a priority, were evaluated. Hospital organization and management and articulation of services are among them. This national improvement guideline, among other reasons, justifies the relevance of this project.

Amid the many members of the SNS is the Hospital da Senhora da Oliveira, a public institution located in the centre of Guimarães, where the project of the Kaizen Institute took place. It was

inaugurated in 1991 and in 2002, due to a change in overall healthcare management in the country, it began having management practices that resemble more the ones of a company, enabling its autonomy and emphasizing efficiency-seeking processes and cost reduction. The patients assigned to the Hospital are the ones of the counties of Guimarães, Fafe, Vizela, Mondim de Basto e Cabeceiras de Basto, that serve as a home to nearly 350 thousand people. Hospital da Senhora da Oliveira aims to be a national and international example in the provision of healthcare. Consequently, and aiming to keep the alignment with the change of strategy and management that occurred in 2002, the Hospital must invest continuously in initiatives that increase the productivity of the resources, increase the service level and the quality of the service itself. Additionally, the public expenditure assigned to healthcare in Portugal is below the European Union average, despite the growth observed in health spending per capita. As of 2019, Portugal spent 2 029 euros per capita on health care, 30% below the EU average (on Health Systems and Policies, 2019). This forces all parts of the National Health Service to cut costs in order to maintain the service level and provide the patients with the healthcare quality that justify the amount they spend as taxpayers. The latter is exactly the scope of Kaizen methods and Lean: to provide efficiency gains without losing focus of what should be the end goal of any organization: customer satisfaction.

1.2 Problem Statement and Goals

An organization is an aggregation of groups of people that come together to achieve a given purpose. A hospital, as an organization, is a combination of teams with people of different backgrounds and with different skills that are managed to adequately serve the patient. Doctors and nurses are perceived as the forefront of the hospital. However, they cannot exert their profession without the appropriate means and tools. Given this, it is crucial for the overall well-functioning of a hospital that support services are perfectly aligned to address the doctors' and nurses' needs.

The project developed by the Kaizen Institute in Hospital da Senhora da Oliveira tackles, among others, two important support services: Pharmacy and Provisioning. As of 2020, the year in which the Kaizen Institute and HSOL began working together, several problems were identified and tackled in further phases of the project.

Briefly, regarding the Provisioning, the main problem lies in the execution of plenty of non-value adding activities to supply the references to the services of the hospital, that compromise the service level and increase the number of stock-outs in each service. These non-value added activities include, among others, double stock write off, empty trips in the warehouse and extensive count of the products. There is also a lack of coordination between services and the warehouse - requests are regularly late and the hours of arrival of the material to each service are irregular. The current practices secure a 93% service level and imply 16% of references in stock-out.

As for the Pharmacy, the problems are relatively similar: the services' requests are often desynchronized with the preparation of the medication, which provokes a severe disruption in the services. The routes to be followed to distribute the medication are not standardized, nor the preparation of the medication for each service.

Overall, the internal logistics' resources are underused, the supply route is not optimized, and there is plenty of room for improvement regarding the coordination of the services with the Pharmacy and the Provisioning. The coexistence of four different operating systems undermines the global efficiency of the information flows.

The solution principle for both the Pharmacy and the Provisioning was based on the synchronization of material and information flows that aims at bridging the gap created by lack of communication and standardization between Services and these Support areas.

As for the Pharmacy, the main goals of the Kaizen project encompass the improvement of the productivity of the teams, by improving the flows and the layout, and the reduction of the interruptions to meet extra requests.

The Provisioning intent is to also increase productivity, increase the service level, increase stock rotation and diminish the level of stock-outs, picking errors and inventory deviations.

In a holistic perspective, the project also targets the waste of resources, by creating flow whenever possible, reduce stocks and work from a just-in-time perspective. These concepts will be further developed in the Theoretical Framework.

1.3 Research Questions and Methodology

Considering the quantitative and qualitative targets of the project, the answer to two important research questions are the end goal of the present dissertation:

- **RQ1:** What are the improvement opportunities possible to identify and approach in the Pharmacy and Provisioning, both internally and in the interactions with the services of the Hospital?
- **RQ2:** Would it be efficient to integrate the Pharmacy flow and the Provisioning flow in the same supply system? If so, how can the route travelled by the logistic train be optimized?

The approach followed to answer the prior research questions was mainly deductive, as it consists of the testing and fine-tuning of the application of tools that already exist, whose applicability is already tested and reported as successfully.

Both in the approach for the Pharmacy and the Provisioning, the application of the Lean and optimization methods encompass three major phases: First, a diagnosis phase takes place, where the problems are identified and quantified. Then, the solution is designed alongside the stakeholders of the project to guarantee its feasibility and applicability. The last phase encloses the implementation of the solutions designed in the second phase.

In the diagnosis phase, the approach followed is both qualitative and quantitative, the latter being extremely important in this phase to discover the problems and quantify the gains that would be obtained through the design of solutions. The last phase of the implementation of solutions is qualitative, constructed based on data and direct observation.

1.4 Document Structure

The structure of this dissertation is oriented to the two different research questions posed in the previous section, preceded by an overarching theoretical framework in Chapter 2. Chapter 3 analyzes thoroughly the performance gaps in the Pharmacy from an internal point of view and describes the application of different Lean methods to solve the improvement opportunities identified, and Chapter 4 serves the same purpose for the Provisioning. Chapter 5 grasps the opportunities for improvement of the supply system, which serves as a starting point for the implementations of a mathematical model that aims to optimize the sequence of supply to the services. Chapter 6 reports the results observed after the implementation, and Chapter 7 discusses the results and presents further work to be developed.

Chapter 2

Theoretical framework

This section's purpose is to briefly introduce and present the state-of-the-art in the areas of knowledge used to answer the research questions posed in the previous chapter.

2.1 Lean in Healthcare

Toyota's success achieved through the creation and implementation of the Toyota Production System is globally recognized since its inception in 1945, and it is paradigmatic to some organizations, popularized by its excellent results in reducing costs, increasing quality and marketing profitable vehicles (Jeffrey K. Liker, 2006). It was not immediately clear that Lean could be applied to other areas, but eventually, the practices were extended to other sectors. The rationale behind this adoption is that every organization must take into account cash flow, quality and customer satisfaction, and Lean deals with those areas. Healthcare is not an exception, although it is not clear when and where the adoption of Lean took place for the first time (Grabau, 2012).

Nevertheless, the studies of Young et al. (2004) are reported to be one of the first studies in the area of Lean Healthcare (D'Andreanmatteo et al., 2015). In this paper, it is firstly introduced the concept of Lean Healthcare and the main difficulties of extrapolating the industrial concept to healthcare are highlighted: The first one lies in the definition of the customers and, consequently, of the value. The second relates to the variability of the route that the patients follow depending on the clinical judgements that he or she is subject to. Regardless of the impediments, there is a clear starting point for improvement. According to Hagan (2011)'s research, 95 % of healthcare operations do not add any value. On top of this, healthcare decision-makers are struggling to contain rising costs and must deal with unsteady quality (Porter and Lee, 2013), which makes healthcare a great incubator for Lean. It is believed that this methodology can bring benefits to healthcare as it is a "good way to manage, coordinate, and schedule work practices in any industry" (Ben-Tovim, 2017).

According to Lean theory, the ground for any improvement should be a thorough analysis of the current situation, in terms of waste and value-added (Sloan, 2014). In the Lean scope, value is defined by the customer and has meaning if associated with a product that meets the customer's needs at a specific price and specific time (Womack and Jones, 1996). All the other activities are classified as waste, or commonly, what the customer is not willing to pay for. Waste in manufacturing is classified into seven types, all of which unwind in examples in the healthcare scope (Manos et al., 2006), as seen in the examples recorded in Table 2.1:

Table 2.1: The Seven Types of Waste (adapted from Graban (2012))

Type of Waste	Healthcare example
Defects	Surgical case cart missing an item
Overproduction	Doing unnecessary diagnostic procedures
Transportation	Poor layout, such as the cath lab being located a long distance from the ED
Waiting	Patients waiting for an appointment
Inventory	Expired supplies that must be disposed of, such as out-of-date medications
Motion	Lab employees walking miles per day due to poor layout
Overprocessing	Time/date stamps put onto forms, but the data are never used

From an analysis of the current literature regarding the topic, one can infer that Lean is not a novelty for the Healthcare sector. The most widespread methods, such as 5S, are well-known to the sector and several success cases are reported in academia (as it will be further developed in section 2.2.2). What is not as developed is the holistic and structured implementation of Lean and Kaizen tools throughout the whole Hospital, nor the possibility of linking intuitive and easily implemented Lean approaches that provide quick-wins with more analytical and robust tools. The main purpose of this dissertation is to combine the two and show how beneficial its synchronous implementation can be.

2.2 Kaizen Business System

Kaizen is a Japanese word that means "continuous improvement", a term that materializes in changing organizations for the better, involving everyone, every day, and with little cost to the company (Imai, 2012). Therefore, a Kaizen project is based on low-cost, low risk and easy to implement initiatives that contrast with common innovation processes that are often rather disruptive, require a lot of effort to implement and do not pay off immediately.

According to Kaizen Institute, five fundamental principles guide the Kaizen philosophy:

- **Create Customer Value:** This principle is strictly related to Quality, as the main purpose of an organization should be to deliver goods that match customers' expectations. Consequently, companies should adopt a "market in" philosophy instead of a "product out", meaning that they should aim at understanding customers' needs and adapt their offer to them. This principle is validated by almost every company in the world (Coimbra, 2013).

- **Create Flow Efficiency:** Flow Efficiency is a combination of three other foundations: reduce waste, implement actions to implement end-to-end flow, and pull flow.
- **Be Gemba Oriented:** This principle enhances the importance of going to the place where things take place in an organization to understand the root causes of the problems and create countermeasures to solve them.
- **Empower People:** The People pillar is achieved through the empowerment of everyone who is part of the organization, regardless of the hierarchical level. This involvement is not only attained by hearing and understanding the workers' pains and problems, but also by giving them responsibility and trust.
- **Be Scientific and Transparent:** As with any problem-solving process, Kaizen relies on data to accomplish its function (Imai, 2012). As important as this principle is visualization: every relevant information should be visible to everyone and the problem-solving process should be visual as well.

2.2.1 Daily Kaizen

One of the bases for the continuous improvement culture is Daily Kaizen, a training program earmarked for Group Leaders, Team Leaders and Top Management Leaders. This tool aims at empowering these Leaders to deploy the improvement strategy so that it is traversal to everyone in the organization, from Top Management to Employees (Imai, 2012). Daily Kaizen consists of four levels: Daily Management, Workplace management, Standardization and PDCA Cycle for Process Improvement.

The first level of Daily Kaizen consists of designing and implementing a board for holding team meetings. These team meetings are typically short and their goal is to discuss the team Key Performance Indicators and propose countermeasures to develop the teams' performance so that the target for each KPI is fulfilled. There are several elements to this board, some of them are mandatory. First, it is vital to have a clear and visible agenda of the meeting with the duration and topics to discuss, as well as the time at which the meeting must begin. Also, every participants' presence is registered, to keep track of the ones responsible for any information that was discussed in a given meeting. The most important part of the board is the KPIs. They should be presented clearly and visually so that everyone can discuss them. Another key element is the work plan, where tasks are allocated to the team members. Finally, there is the improvement cycle, or actions plan, where every improvement action that is originated from the KPI analysis or any other discussion should be registered, alongside the worker responsible for implementing and the date (Imai (2012) and Ribau and Félix (2013)).

Imai (2012) manifests the benefits of Daily Kaizen through a case study in a weaving plant in Brazil, which reported, among others, efficiency gains accretion by 26% and a 25% reduction in

defects. Moreover, it is highlighted how "Daily kaizen gave a better definition of responsibilities and greater efficiency in reaction to deviations" in the organization mentioned in the case study.

2.2.2 5S

The 5S is one of the many tools of Kaizen that provides a structured approach to workplace organization. As any other Kaizen tool, is based on commonsense and it requires little monetary investment, which often compromises the attractiveness of the tool for managers (Imai, 2012). The five steps of this method are:

- *Seiri*: sort necessary and disposable items and keep only the first
- *Seiton*: arrange all indispensable items in order
- *Seiso*: keep the working environment clean, and everything totally functional
- *Seiketsu*: systematize and make sure the cleaning and sorting are sustainable
- *Shitsuke*: standardize the first four S and create a habit out of them

The application of this methodology is not new to the Healthcare sector as is it clear the benefits it may bring. The CEO of ThedaCare Health System in Wisconsin values the reduction of time spent on non-value-added activities after 5S as two and a half hours on an eight hours shift (Graban, 2012). Another case study quantified the gains of 45 5S events that took place between 2008 and 2010 as over 4 million dollars in revenue capacity, 509 thousand dollars in saving and 215.8 square meters of space created (Nahmens et al., 2011). In the recent past a Hospital in Vigo, Spain, reported having collected more than 25 thousand euros of savings through the implementation of 5S in the medication storage of hospitalization departments (Gayoso-Rey et al., 2020).

Recently some organizations began including a sixth S, that tackles the issue of Safety in the workplace (Graban, 2012). Whilst the importance of Safety is undeniable, in some environments, including Healthcare, is already inherent to the Organization. Therefore the literature regarding this 5S extension is scarce, contrarily to the original 5S.

2.2.3 Value Stream Mapping

Heretofore, the methodologies presented only allow improvement in isolated processes and teams. One way in which this improvement can be escalated to create a thoroughly, sustainable and organized lean enterprise is through Value Stream Mapping. Similarly to Lean and consequently, Value Stream Mapping was born in Toyota, although it was not formalized until 1999 when Rother and Shook wrote the first edition of "Learning To See" (Jeffrey K. Liker, 2006). According to the Rother and Shook (2003), the value stream is defined as "all the actions (both value-added and non-value added) currently required to bring a product through the main flows essential to every product". These flows are subdivided into material and information flows. The

first concerns the movement of materials through the factory. The latter is responsible for deciding, in a given process, what it should produce next (Rother and Shook, 2003). Figure 2.1 shows the typical roadmap for VSM. It begins by selecting a product family on which one will want to work. Then, the current state of the production process is depicted by collecting information on the shop floor. The conversion of a current-state to the future-state drawing is made by identifying wasteful processes flows and come up with solutions to discard them (Chase et al., 2018).

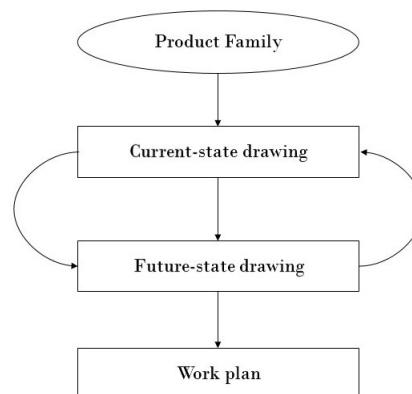


Figure 2.1: Value Stream Mapping sequence. Adapted from Rother and Shook (2003)

Similarly to Lean, VSM was a concept that was well developed in manufacturing well before its transition to Healthcare. It is highlighted by Radnor et al. (2012) that often lean applications in Healthcare lack integration, meaning that disjointed tools are widely used within the sector, yet they were not inserted in a "more comprehensive programme of change". Value Stream Mapping aims at bridging that gap, making it possible to bypass the inefficiency of "carrying out random improvement initiatives that do not bring solid results to the bottom line (Sim and Rogers, 2009 *apud* (Tortorella et al., 2017)). In this sector, VSM is one of the most widely used tools for lean implementation. Most of the literature regarding VSM concerns two workflows: administrative process and patient treatment process (Shou et al., 2017). This study also quantifies the benefits of implementing VSM in administrative processes: 35% reduction of customer complaints, 41% reduction of employees overtime, and reduced processing time of critical business processes from two days to one day. Another interesting remark made by the author is that techniques for improvement that are extensively used in manufacturing are underdeveloped in the Healthcare VSM approach: for instance, only 1,14% of the studies report having adopted practices supported in Pull supermarket theory. More recently, Marin-Garcia et al. (2021) concludes, in his state-of-the-art review of VSM in Healthcare, that it is a technique suitable to all areas. Nevertheless, the lateness of the transition to Healthcare - in fact, until 2015, there was little research material on the topic - undermines the effectiveness of results, indicating that the methodology should be developed in order to be fully fitting to the Healthcare sector.

2.2.4 Total Flow Management

Pull-flow thinking is the core of the Toyota Production System. It means coordinating the supply chain in order to obtain an optimal material flow and an optimal information flow (Coimbra, 2013). Total Flow Management is an equivalent term for this tool used to convey the idea of kaizen in logistics and supply chains. The difference between push and pull systems is important and has been around since the term "Lean" was coined. Working in a pull-flow logic means that "nothing will be produced until is needed" (Chase et al., 2018). Taking a manufacturing example, the Pull-flow system can be visually represented by Figure 2.2. Every stage in the production process is linked and material starts flowing whenever there is demand from the customer (Chase et al., 2018).

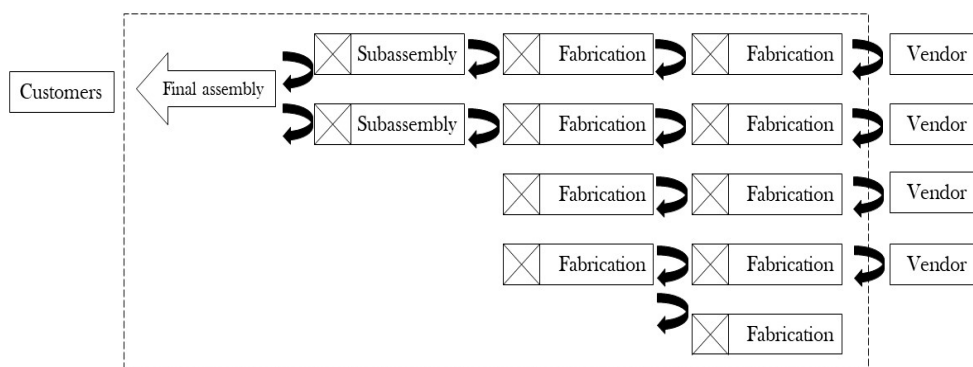


Figure 2.2: Lean Production Pull System. Adapted from Chase et al. (2018)

Contrastingly, a push system will, in each stage, produce as many units as it can regardless of the needs of the next stage. These systems work in batches, creating a waste of transport and inventory (Imai, 2012). Hence, the ultimate goal of pull-flow thinking, or Total Flow Management, is to eliminate these wastes, working in a one-piece flow, reducing total lead time, and consequently increasing customer satisfaction, lowering working capital needs and increasing productivity (Coimbra, 2013).

The Total Flow Management (TFM) model consist of three pillars: Production Flow, Internal Logistics Flow and External Logistics Flow. Only the Internal Logistics Flow is within the scope of this dissertation, so it will be further developed in the next section.

2.2.4.1 Internal Logistics Flow

The internal logistics flow comprises the handling of all the management of the internal supply process, storage, transportation and distribution of goods within the organization (Shepherd and Günter, 2010). The Total Flow Management model describes five categories to achieve pull-flow in the internal logistics, as shown in Table 2.2.

Table 2.2: Pull-flow in the internal logistics - adapted from Coimbra (2013)

Category	Goals
Supermarkets	Simplify and increase the picking of parts
Mizusumashi	Transports parts to the points of use, liberating workers from that task
Synchronization	Simplify the coordination between the supply of parts and production
Levelling	Make lines and machines scheduling as efficient as possible
Production Pull Planning	Calculating production orders by the consumer pull rules

The supermarket has a simple *modus operandi*: if between two sequential stages of a process there is a supermarket, it means that the upstream process must replenish what the downstream customer took away. This implies a violation of the one-piece flow principle, so it is not the preferred choice. However, it is best than a push system (Jeffrey K. Liker, 2006). The mizusumashi is also a simple concept that applies to the "logistics worker who does the internal transportation of goods, using a standard fixed cycle route" (Coimbra, 2013). The other three concepts will not be discussed as they are not in the scope of this dissertation.

Extending the concept of Logistics to the Healthcare sector, one can argue that the supply chain has some characteristics that are not easily transposed to the manufacturing sector. A typical hospital supply chain resembles the one in Figure 2.3.

Lean Logistics applied to hospitals began to gain relevance in the early twenty-first century (de Vries et al., 2011), accompanying the identification of logistics as a key lever for cost management in Healthcare. Nonetheless, the literature early acknowledged the effectiveness of Just in Time and stockless material management in improving hospital operations (Kim and Schniederjans, 1993 apud Volland et al. (2017)). While across the literature the benefits are commonly remarked, several authors discuss the difficulties of implementing these practices. Mazzocato et al. (2014) not only highlights benefits achieved in available case studies - "improved quality, access, efficiency and reduced mortality", but also enhances that the projects up to that date are often too narrow and could benefit from senior management involvement to improve sustainability, solution retention increase, and from viewing continuous improvement in a long-term perspective. Gary Jarrett (1998) early states that although manufacturing and healthcare share issues regarding distribution, inventory control and product production, this sector was reluctant to embrace the gains from applying just-in-time systems. Later on, Volland et al. (2017) acknowledges that both academia and practitioners recognize the potential of hospital logistics optimization.

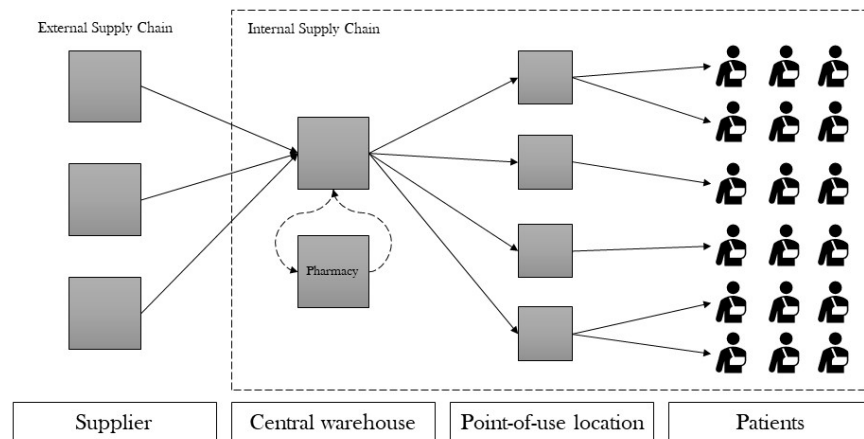


Figure 2.3: Model of a hospital supply chain. Adapted from Volland et al. (2017)

Whilst literature regarding inventory management and policies is vast, the topic of internal distribution and scheduling seems to have space for exploitation. There is also a lack of standard practices among material distribution (Volland et al., 2017).

2.3 Optimization

Optimization is the way in which one can find the best possible solution for a given problem. There are many methods to solve these problems. However, regardless of the method followed, it is extremely important to correctly define mathematically the problem (Amiri et al., 2017). Then, the optimization technique chosen will depend, among other things, on the complexity of the problem.

By definition, if the number of decision variables and constraints is relatively small, the Exact methods are expected to deliver a better solution. However, as the number of decision variables and constraints grows, the computational time can be an important criterion to opt for Approximate methods.

2.3.1 Exact Optimization methods

One of the branches of optimization is the Exact methods. Simply put, exact methods provide an optimal solution to the problem formulated (Rothlauf, 2011). This branch can be sub-divided into Iterative and Enumerative methods. An example of an Iterative method is the Simplex method,

which searches among the basic feasible solutions, starting at a feasible solution and then iteratively checks if the value of the objective function decreases (Arora, 2012). Linear Optimization Problems, i.e., problems in which the objective function depends linearly on the decision variables (Rothlauf, 2011), can be solved using the Simplex method.

2.3.2 Approximate Optimization methods

In contrast with Exact methods, Approximate Optimization methods are not guaranteed to provide the best solution for a given problem. The terms "Approximate methods" and "Heuristic methods" can be used interchangeably (Rothlauf, 2011). Often, heuristics are counterposed with algorithms regarding problem-solving (Hamad, 2007), as algorithms are a structured way to solve problems and retrieve an "exact and reliable solution", whilst heuristics are experience-based and only work in some cases. Another field of study relates to metaheuristics. Metaheuristics are heuristics that are not problem-dependent, so it is an approach more structured than Heuristic applications, and typically delivers results that are closer to the optimal solution (Blocho, 2020).

Chapter 3

Pharmacy improvement opportunities

This chapter aims at explaining the situation at the beginning of the project, the method followed to design the solutions and the solutions' implementation in the Pharmacy. This Chapter tackles the answer to the first Research Question posed in Chapter 1.

All of the following analysis and previous solution designs were made resourcing to a team composed of KI consultants and a team of the HSOL, composed of representatives of all the relevant functions in the Pharmacy.

3.1 Current Situation Mapping

The Pharmacy at HSOL manages three important material flows: Traditional, Single-dose and Production. The Single dose relates to the flow of medication prescribed by a doctor to a patient. The Traditional flow includes medication of general use that is not assigned to a patient. Lastly, the Production covers the manipulation of drugs to support oncological treatments. Out of these three, the Traditional flow was the one chosen to map and act on, as the Production only affects one of the many services of the Hospital, and the Single-dose is related to many bureaucracies regarding patients' discharge.

Figure 3.1. describes the steps executed by each one of the four participants in the Traditional medication distribution. In this process several problems can already be identified:

- The stock level is not always verified by the nurse that often orders the maximum for each reference.
- The nurse has to search for the reference in the system and introduce the quantity to order manually, every time the quantity to order is different from the stock keeping unit
- Waste of printing the order although it is already in the system
- The Pharmacists does not add any value throughout this process

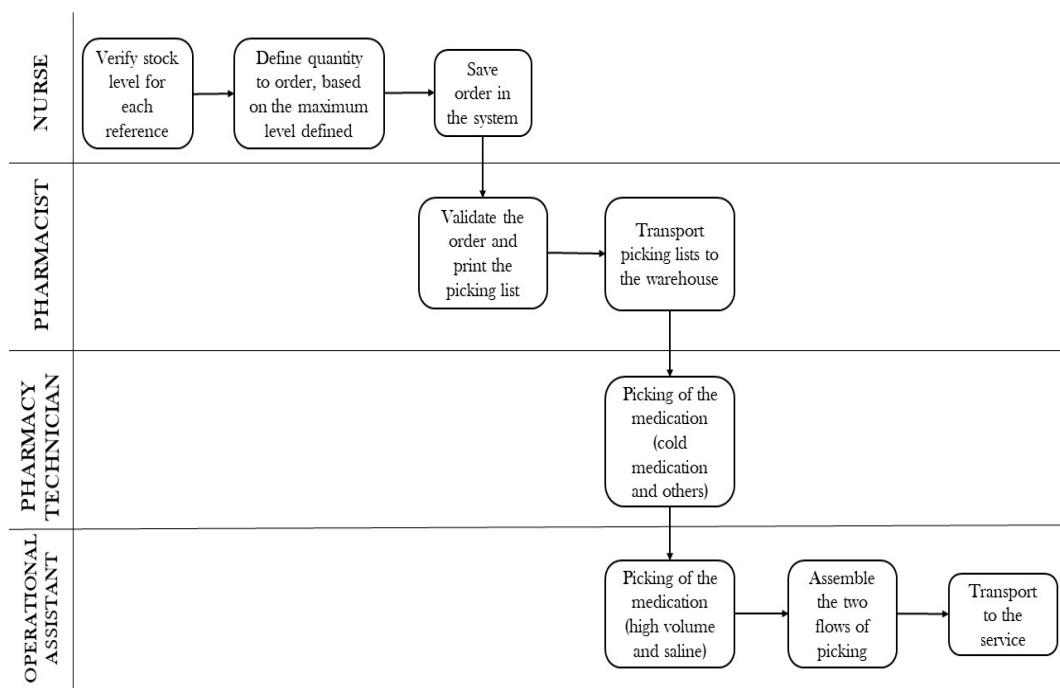
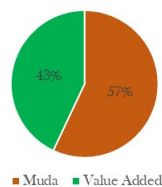


Figure 3.1: Traditional Flow Mapping

Another initiative common to VSM workshops is a *Muda/VA* analysis. Recalling the concept of *muda*, this analysis aims at identifying which activities in a given process do not add any value to the final product - commonly defined as *muda* or waste. The analysis is described in Figure 3.6. Picking is the only task that brings any value. Waste of movement is necessary and can be reduced using an optimized layout. Searching and noting are activities that do not add any value and should not be necessary and therefore can be totally eliminated.

Task	Time (seconds)	Muda/VA	%	Potential reduction	New time (seconds)	Productivity increase
Picking	124	VA	43%	0%	124	62%
Movement	104	Muda	36%	50%	52	
Noting	27	Muda	9%	100%	0	
Searching	31	Muda	11%	100%	0	

Current State Muda/VA Analysis



Future State Muda/VA Analysis

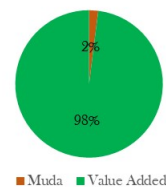


Figure 3.2: Muda/VA Analysis

The previous analysis was related to the flow of information. To complement this information, a map of the flow of materials was needed. The result was the one represented in Figure 3.3. The white line represents the flow of material. The orange is the movement of the technical assistant that works directly with the Production. The red line shows the movement of the administrative that handles the reception of the orders. The blue is the movement of the pharmaceutical that handles the flow of narcotics. Finally, green represents the flow of transportation of Oxygen. The main opportunities identified with this analysis were the following:

- The layout is not adjusted to the reception of the material (the administrative must move in order to acknowledge the reception of the material).
- There is not a specific zone to store the received material
- Displacement to store material in the stock area
- Crossing of material flows and operational assistants (Single-dose and Traditional)
- Elements strange to the department need to enter the Pharmacy

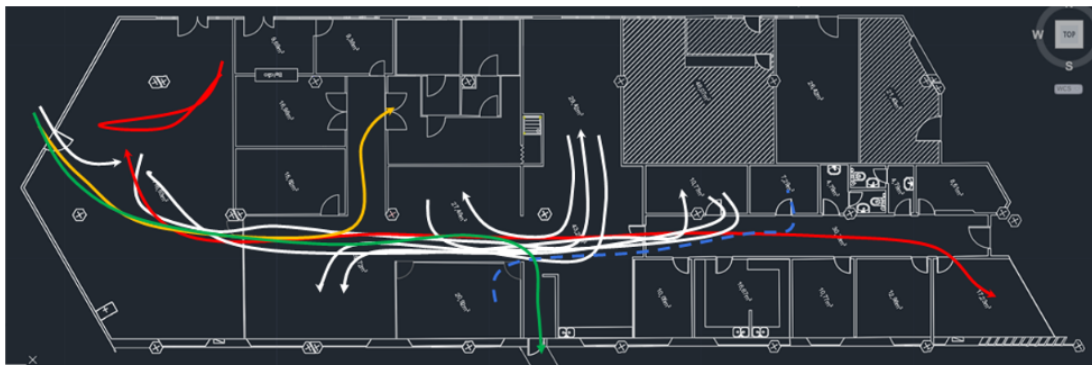


Figure 3.3: Current Layout of the Pharmacy

After this analysis, it was clear that the reception of material had the greatest opportunity for improvement. Therefore, it was mapped in more detail, alongside a multidisciplinary team composed of a Pharmacist, an Operational assistant, an Administrative assistant and a Pharmacy Technician. The result of the current state mapping is shown in Figure 3.4

The opportunities identified in this process were:

- In the administrative reception, the administrative needs to check whether or not the order is destined to the Hospital.
- The quantities received of each reference are not standardized.
- Some references are located in the corridors.
- There is not appropriate signaling of the orders ready to check administratively

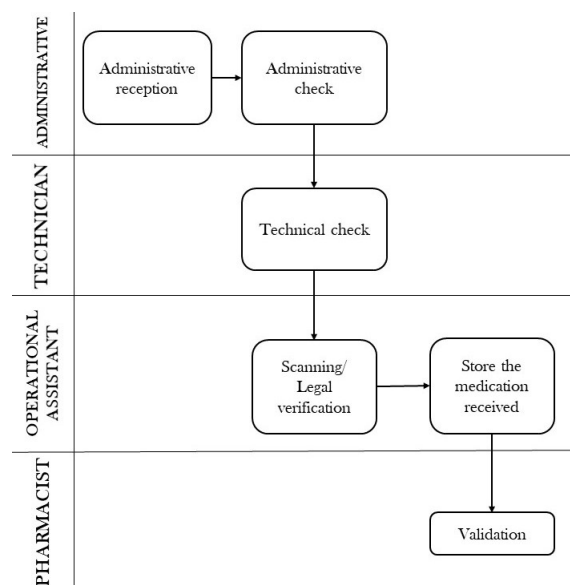


Figure 3.4: Process Mapping of the Reception of the material

- In the technical check there are errors in the quantities in the transport guide
- Debits are not made in real-time
- Stock errors in the technical check
- In the legal verification, the quantity, lot, and validity is manually checked.
- Time spent looking for the check sheet and associate the sheet with the box
- In the storage of the medication, the layout is not adjusted and there is not a standard route.

This thorough analysis of the current situation served as the baseline for the design of the solutions.

3.2 Solution principles

Recalling the opportunities identified, the solution principles implemented were:

- Supermarket implementation in the medication of the Traditional flow - solves the problem of manual stock level verification by the nurse.
- Handling unit - tackles the need for the extensive count in the picking of medication, thus reducing the time allocated to this activity.
- Design of a new layout to bridge current improvement opportunities.
- Standard reception and storage of material.

- Daily Kaizen to provide basic stability to the teams and implement a continuous improvement culture in the Pharmacy. The indicators to be featured on the board will vary from team to team.

3.2.1 Supermarket implementation

As explained in the Literature Review, the supermarket has the function of securing the replenishment of parts between two different stages of the process. In this case, the supermarket is implemented in between the Pharmacy and each service to increase the service level and release the nurses from logistic operations. The implementation of a supermarket in between two stages requires the definition of a Reorder Point (ROP) for each reference. By definition, the Reorder Point (ROP) should be calculated by summing the average daily consumption times the Lead Time of Replenishment and a Safety Stock (SS). The definition of a SS is adaptable to the needs of each supermarket and in this case, it was defined that for critical products it should be variable according to the typology of the product. The nurse responsible for the warehouse should evaluate whether the stock-out of that product causes a serious disruption in the service and/or the pattern of consumption is not regular, if so, they should pick a SS of 5 days of average consumption. Otherwise, they can pick 3 days of average consumption. These formulas are summarized in Equation 3.1, 3.2 and 3.3

$$ROP = AverageDailyConsumption * LeadTimeofReplenishment + SafetyStock \quad (3.1)$$

$$SafetyStock1 = AverageDailyConsumption * 5 \quad (3.2)$$

, for critical products and/or products with irregular pattern of consumption

$$SafetyStock2 = AverageDailyConsumption * 3 \quad (3.3)$$

, for non-critical products and/or products with regular pattern of consumption

After the implementation of the supermarket pull system in each one of the services covered by the Traditional Flow, one is expected to see a reduction of the number of stock-outs, as they were previously influenced by the manual and sometimes inaccurate extensive manual counting of the stocks. Also, the time spent by the nurse ordering the material will be barely negligible, as he or she will only need to scan the bar code of the product to confirm that the product was consumed.

3.2.2 Handling unit

An intuitive approach to minimize the time spent picking the medication was the modification of the handling unit in the information system. Before, the system defined by default a handling

unit of one, regardless of the quantity in the supplier's box, which means that if, for instance, the nurse ordered three dressings, and the box has ten, the responsible for picking the medication for that service has to open one box and count three dressings. By changing, for each reference, the handling unit, for a unit that is more suitable for both the Pharmacy and the services implied, one can expect to see the picking time reduced, and the reduction of the number of stock-outs intensified.

3.2.3 New layout

In light of the problems identified in the current situation mapping, a new layout was proposed to minimize waste of displacement and to surpass the other problems. The first thing to do was to completely separate flows of movement to increase productivity and organize traffic within the Pharmacy. As one can see in Figure 3.5, the white flow, which represents the material flow, does not cross any of the other flows. The movement of the administrative to receive the material, evidenced by the red line, was drastically reduced, and so was the displacement of the technical assistant that works directly with the Production (orange), by simply placing a door near the Production area. The flow of Oxygen (green) was changed by placing another door next to the main one. The picking of the Traditional flow will be largely improved, as the picking of large volumes was moved to another area, next to the Pharmacy, and the picking of small and medium volumes will be in the shelves placed in the lower-left corner of Figure 3.5. This change of layout is expected to increase the productivity of all areas, increase the safety of the area due to the enlargement of critical areas (flammable materials), and also increase the organization of materials. Due to the COVID-19 pandemic, the Hospitals need to have a much larger stock of salines, so they had to be moved to the corridor. The uncertainty of the situation required a new space for this extra stock of salines, which at the same time will greatly increase the picking of all medication and the flow of people through the corridors.



Figure 3.5: New layout of the Pharmacy

3.2.4 Standard reception and storage of material

Recalling the problems identified in the previous section, and the reception and storage of material being identified as areas with great opportunity for improvement, the solution principles applied were the following:

- Scheduling of the reception and storage of material - previously the responsibility of reception and storage of material was not assigned to anyone in particular. Now, each month, there is a clear assignment of responsibilities. The template for the scheduling can be found in Appendix A
- Segmentation of storage routes and cars by storage zone. In Figure 3.6 it possible to see the routes defined according to the storage zone. Previously there was no standard and the medication was stored randomly as it arrived at the Pharmacy. To minimize waste of transportation, the cars in Figure 3.7 are filled to their fullest and then the medication is stored according to its route.



Figure 3.6: Storage routes



Figure 3.7: Storage cars

- Storage standard and *kamishibai* - an important criterion in the storage of medication is FEFO (first expired, first-out), meaning that the medication that is closest to the expiration date should be the first to be used. To guarantee that this criterion is followed, a standard was made visible to everyone. The standard can be seen in Figure 3.8. The compliance with this standard was checked weekly using a *kamishibai* card, which can be seen in Figure 3.9. Every week, a set of ten medicines were chosen by a Pharmacist that is also responsible for answering three questions: [1] Is the medication stored in the right place? [2] Is the medication within the expiration date? [3] Was the FEFO criteria fulfilled and the storage standard followed? If the answer to the question is affirmative, it counts as one point in thirty possible. The green part of the card should be displayed if the punctuation is higher than fifteen. This way the team knows how to improve each week, knowing in which criteria they failed. The punctuation of the *kamishibai* audit is displayed alongside the productivity.

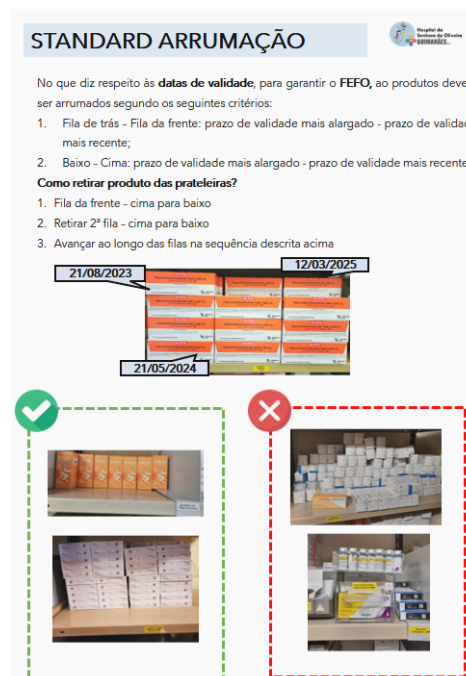


Figure 3.8: Storage standard

- Measuring the productivity of reception and storage - the display of this KPI visually prompted a continuous improvement culture into everyone involved in the reception and storage of material. The productivity was measured as stated in Equation 3.4

$$Productivity = \frac{Number\ of\ units\ received}{Working\ hours} \quad (3.4)$$

This way, the team can see whether or not the improvement initiatives and the compliance to the new standards actually upgrade the way their work is carried out.

#	Artigo	Artigo no local certo?	Artigo dentro da validade?	Cump. do FEFO e standard de arrumação?
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Auditor: _____ Data: _____

Figure 3.9: Storage kamishibai

3.2.5 Daily Kaizen for basic stability

Traditional

Typically the ground for any implementation of Lean and Kaizen methods begin with the establishment of a formal moment of communication between all team members. This moment, whose duration varies from team to team according to its availability and work schedule, has a defined and standardized agenda. For the Traditional team of the Pharmacy, this moment was created to analyze indicators, discuss improvement opportunities, and check the status of the improvement initiatives using the PDCA cycle (Plan, Do, Check, Act). The Indicators to analyze were defined alongside the team, for some of the four QCQM (Quality, Cost, Delivery, Motivation) dimensions. The indicators that made sense, in this case, were the number of debit errors committed, the number of references on which the physical stock is higher or lower than the stock in the system, and the non-compliance with the schedules defined for the preparation and delivery of medication for each service. Striving for excellence in each of the activities associated with the Traditional flow, one can expect to see a lower value of each of these three indicators. Each time one value of the indicator does not stand within the acceptable limit defined, or there is a negative trend, the reason should be identified and addressed within the Daily Kaizen meeting. Once there is an improvement initiative, it should be added to the Plan step of the PDCA cycle, and follow the cycle until it is part of the regular functioning of the team.

Single-dose

The Daily Kaizen board for the Single-dose followed a similar approach, but the KPIs were slightly different because the scope of the work is distinct. It shares with the Traditional team

Hospital da Senhora da Oliveira
GUIMARÃES

KAIZEN DIÁRIO
FARMÁCIA - TRADICIONAL

AGENDA

Agenda da Reunião

Respostas: 08:00
Horário: 10
Duração: 10

ANTES DA REUNIÃO	DURANTE A REUNIÃO	DEPOIS
1. ATUALIZAÇÃO EM REUNIÃO	1. REGISTO DAS PRESENCAS	0,0
	2. REGISTO DO PLANO DE AÇÕES	1
	3. ANÁLISE DE INDICADORES	7
	4. ATUALIZAÇÃO PLANO DE AÇÕES	1
	5. CONCLUSÃO EQUIPA	0,0

MAPA DE PRESENCAS

Mapa de Presenças

PDCA

PLAN
PLANEAR

CHECK
EM VERIFICAÇÃO

DO
EM CURSO

ACT
CONCLUÍDO

INDICADORES

Indicador: # ERROS DE DEBITO

Respostas: 08:00
Horário: 10
Duração: 10

Indicador: # INCUMPRIMENTO HORÁRIOS

Respostas: 08:00
Horário: 10
Duração: 10

PLANO DE TRABALHO

NOVIDADES

Figure 3.10: Template of the Traditional team Daily Kaizen Board

the KPI of compliance with the schedules, and it has another indicator that reflects the correct utilization of the Kardex (the equipment that retrieves the medication according to the doctor's prescription). If one Pharmaceutical assistant has to pick medication outside the Kardex for a given prescription, it is because the Kardex was not well loaded. The count of the causes which originated the picking outside the Kardex was also an important indicator and allowed the team to act on some causes using the PDCA cycle.

Production

The structure of the Daily Kaizen meeting in the Production is relatively similar to the previous teams in terms of non-compliance with schedules. In addition, it displays how many of the daily

repetitive tasks are fulfilled (see Appendix B for the templates). The one that is different from the other KPIs is the one that relates to the Cost dimension, which reflects the cost incurred in the waste of drugs needed for the preparation of oncology treatments. The dashboard that shows the savings or the increase in waste in monetary terms can be seen in Figure 3.11. In the dashboard, the Pharmacist can see the reduction or increase in waste of the drugs he or she is working on, as it is not possible to reduce waste in every drug. They can compare the waste incurred in the previous week with the current one, as well as the average of the previous month with the antepenultimate.

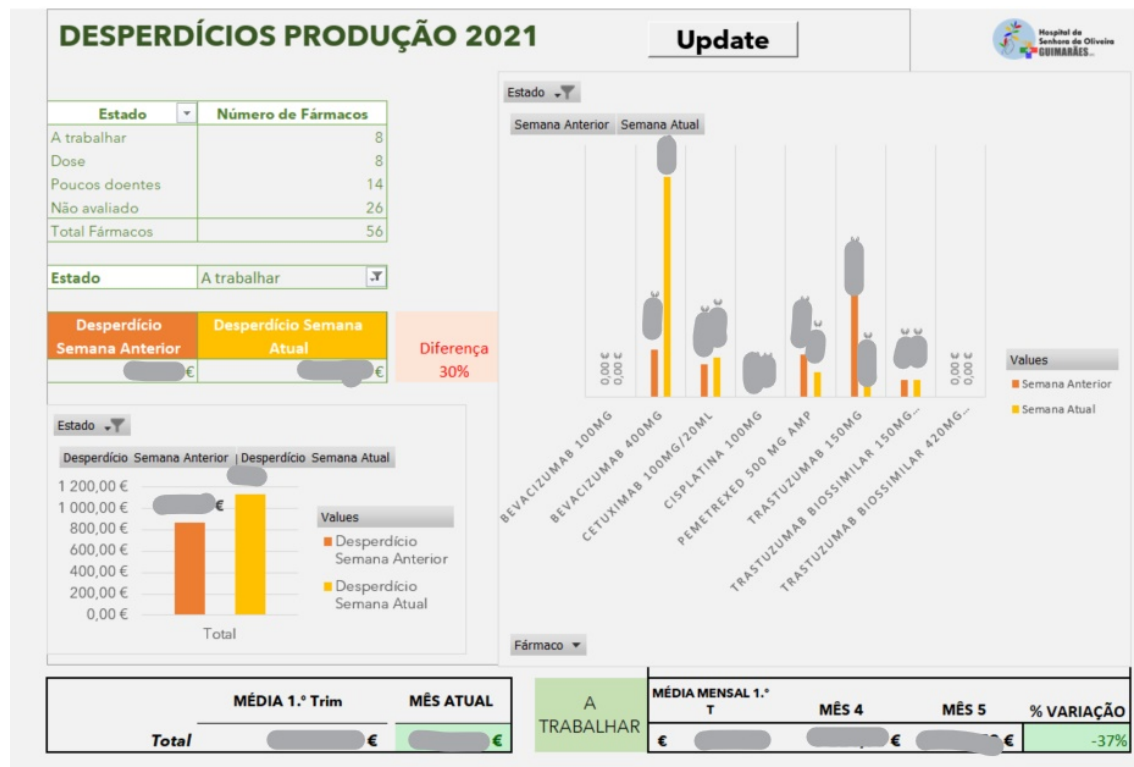


Figure 3.11: Production waste in monetary terms - Dashboard

Chapter 4

Provisioning improvement opportunities

This chapter shows how the solution for the Provisioning team was defined and implemented. Similarly to Chapter 3, it starts with an analysis of the current situation, the main improvement opportunities and the solutions to tackle each one of them, trying to answer the first Research Question posed in Chapter 1.

All of the following analysis and previous solution designs were made resourcing to a team composed of KI consultants and a team of the HSOL, composed of representatives of all the relevant functions in the Provisioning.

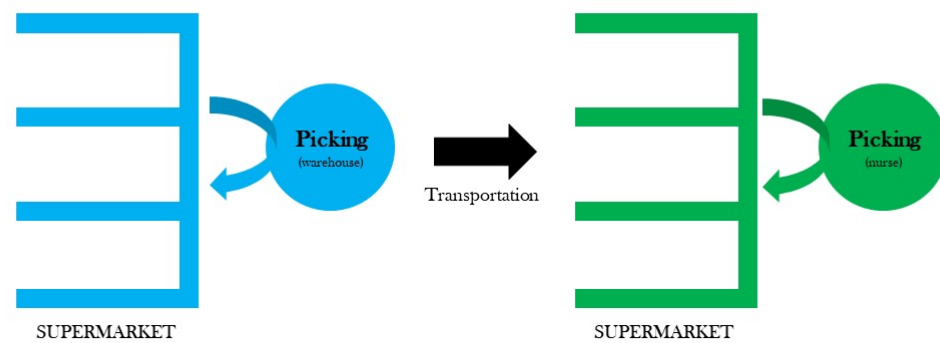
4.1 Current Situation Mapping

The Provisioning is responsible for supplying consumables to each one of the services of the Hospital. As of 2020, the main tasks associated with this process include the reception and processing of the orders from the services, the purchasing from suppliers, picking and subsequent distribution to the service. Unlike the Pharmacy, the flow of materials is already designed in light of the Pull Flow system theory, visually explained in Figure 4.1

To evaluate how efficient the current practices were in providing each service with an adequate quantity, it was analyzed the service level and the number of stock-outs from March to September 2020. During this period, the average service level amounts to 93% (see Figure 4.2

The main problems identified regarding this process were:

- Nonexistence of an algorithm with defined rules that do not allow a parameter optimization
- High coverage for references with a low Lead Time



For each reference, the service defined a Reorder Point (ROP).

Whenever the Stock in the service is lower than the ROP, the system triggers the need to the warehouse of replenishing that reference up to the ROP.

The warehouse also works with this Pull Flow Logic. Each reference has a ROP and if the stock at the warehouse is lower, an order to the supplier is made.

Figure 4.1: Supermarket Flow

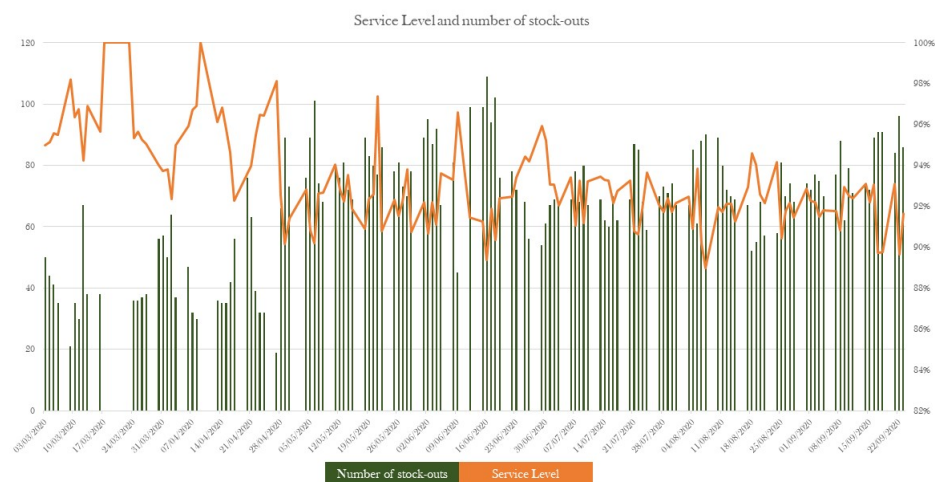


Figure 4.2: Service Level and Number of Stock Outs in 2020

Another area tackled in the VSM was the Picking. Similarly to the Pharmacy, a *Muda/VA* Analysis was conducted, as shown in Figure 3.9. Additionally, a Spaghetti diagram was drawn to understand the movements that each picker does in the warehouse (Figure 3.10).

These two analysis combined highlighted the following problems and improvement opportunities:

Service	Task	VA / Muda	Duration	%
UCA Supermarket	Movement	Muda	176	10%
UCA Supermarket	Picking	VA	32	2%
UCA Supermarket	Counting	VA	197	12%
UCA Supermarket	Cuts	Muda	163	10%
UCA Supermarket	Arranging	Muda	151	9%
UCA Supermarket	Other	Muda	38	2%
Cardiology Supermarket	Movement	Muda	177	11%
Cardiology Supermarket	Picking	VA	19	1%
Cardiology Supermarket	Counting	VA	85	5%
Cardiology Supermarket	Cuts	Muda	17	1%
Cardiology Supermarket	Arranging	Muda	85	5%
Cardiology Supermarket	Other	Muda	19	1%
Non registered time	Movement	Muda	521	31%

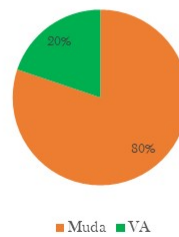
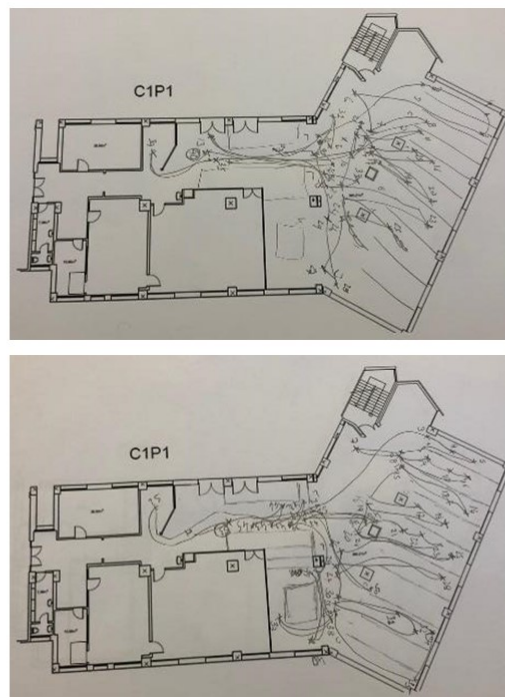
Figure 4.3: *Muda/VA* Analysis for the Provisioning

Figure 4.4: Spaghetti Diagram of the picking for two different services

- The picking car does not fit in the corridor. Therefore, about 50% of the movement is done empty-handed

- The picking operators validate the quantity needed for each service ("Cuts") and round up to the quantity that comes in the supplier box
- There is not a defined unit of movement for each reference, so every quantity to provide is manually counted by the pickers
- Picking is not directly made to the transportation car, so there is the need of arranging the products after
- Picking is made with a paper sheet
- As there is not any computer support, after the picking the quantities to provide to each service needs to be uploaded in the system
- Some materials do not have a fixed position, originating high searching time
- The corridors are not dedicated, which may cause waiting times between the operators

4.2 Solution principles

Given the opportunities identified in the Value Stream Mapping, the solution principles to tackle them were:

- Periodical review of the Reorder Points for each reference
- ABC/XYZ analysis for warehouse optimization
- Handling unit sent to the Services, instead of the extensive count of products
- Multi-order picking and other improvements
- Daily Kaizen for basic stability
- 5S in the warehouse of each service

4.2.1 Periodical review of the Reorder Points for each reference

One of the problems identified in the VSM phase was the high coverage for a product with a low Lead Time. As of 2021, most of the services of the Hospital functioned with supermarkets and had daily deliveries. However, some of the ROPs defined had not been reviewed since the beginning of the supermarket utilization. Due to COVID-19 and other factors of disruption, some of the ROPs were outdated and needed periodical review based on real data of consumption. This review was made on a yearly basis, but it was common that the nurses did not have the time to do this review and they left everything as it was.

To solve this problem, it was created a standard for this periodical review, that started being carried out semiannually. Looking back on the pattern of consumption of the last six months, through an Excel file built with Power-Query to read directly from the files that can be taken from GHAF (*Gestão Hospital Armazém e Farmácia* - Hospital Management of Warehouse and Pharmacy), one can calculate the daily average. Taking the daily average, it is possible to calculate the consumption throughout the Lead Time of Replenishment, and, as seen in the Pharmacy, calculate the ROP based on the consumption. Recalling the formulas for calculating the ROP - Equations 4.1, 4.2, 4.3:

$$ROP = AverageDailyConsumption * LeadTimeofReplenishment + SafetyStock \quad (4.1)$$

$$SafetyStock1 = AverageDailyConsumption * 5 \quad (4.2)$$

, for critical products and/or products with irregular pattern of consumption

$$SafetyStock2 = AverageDailyConsumption * 3 \quad (4.3)$$

, for non-critical products and/or products with regular pattern of consumption

The file that was presented to each nurse can be found in Appendix C. The filling of this file was preceded by a face-to-face explanation to the nurse of the dynamics of the supermarket.

4.2.2 ABC/XYZ analysis for warehouse optimization

The ABC/XYZ is an analysis of the rotation and variation of consumption of a given product. The A, B and C classification aim to identify products by their rotation. According to the Pareto principle, the first 20% of products (ordered from the percentage of total transactions) account for 80% of the total units sent to the services (higher rotation), in this case. Up to 95% are B products and the last 5% are C products. The X, Y and Z stand for the demand pattern. X products' consumption is regular, the Y products present strong fluctuations, and the Z products are extremely irregular or random. The X, Y and Z classification also follow the Pareto principle, if ordered by ascending coefficient of variation ($CV = \text{Standard Deviation}/\text{Average}$).

In that sense, it was made an analysis classifying products regarding rotation and demand patterns. According to that classification, the storage place was defined to optimize the picking. The classification is described in Figure 4.5.

The Location is defined relatively to the exit of the central warehouse (a product that is classified as "Very Close" is very close to the exit - minimizes the distance travelled to access a product that is picked many times during the day).

ROTATION	DEMAND PATTERN	LOCATION
A	X	VERY CLOSE
A	Y	CLOSE
A	Z	FAR
B	X	VERY CLOSE
B	Y	CLOSE
B	Z	FAR
C	X	VERY CLOSE
C	Y	FAR
C	Z	FAR

Figure 4.5: Relative location of the products according to rotation and consumption pattern

4.2.3 Handling unit sent to the Service, instead of the extensive count of products

Similarly to the Pharmacy, in every product, a handling unit was defined in the GHAF system (the unit that is transported to the services) equal to the received unit. The system automatically rounds up the units that should be sent to the service to the nearest multiple of the received unit from the supplier. For instance, if the warehouse receives a box from a supplier that contains 10 syringes, and to replenish one service on a given day 12 syringes are needed, the warehouse should send 20 (2 boxes). However, this system has one important trade-off: for one service it could be indifferent to send one box or a given number of units, because it has space or because the product has high rotation and is always being used. For another service, it could be the case that the product is hardly used and therefore the box occupies a lot of space that would be better used with other references. Once the handling unit is defined it becomes a property of the product (not of the product in each service - the handling unit cannot be changed according to the services' preference). Consequently, the implementation of this handling unit needs to take into account this important trade-off.

To solve this problem, and as the GHAF system still allowed services to make Internal Orders (orders outside the supermarkets, with which the nurses could order whatever product they wanted to in the chosen quantity), the products in which the handling unit was not appropriate to the service, the stock was managed via Kanbans, which meant that on those products, instead of the stock being electronically managed, there was a visual alert that the product needed to be ordered through an Internal Order. An example of a Kanban can be seen in Figure 4.6.

4.2.4 Multi-order picking and other improvements

Recalling the *Muda/VA* analysis done to the picking, the movement took a large part of the task. However, movement cannot be eliminated, only minimized. Considering this, this initiative aimed at reducing the movement that the pickers needed to incur to replenish the supermarkets, by picking simultaneously for two different services. By the time Kaizen started working at the warehouse, picking was done empty-handed, the cars did not get into the corridors, so there was a lot of unnecessary movement. In one of the first workshops made with the team, which resulted

Hospital da Senhora da Oliveira GUIMARÃES		Kanban	Enc. Interna
OBSTETRÍCIA			
Designação	Localização		
Lista de verificação pré-operatória	2A		
		Ap	
Ponto de encomenda	1		
Quantidade a encomendar	3		
 530300817			

Figure 4.6: Internal Order Kanban

in the identification of problems and solutions shown in Figure 4.7, it was agreed that it was of paramount importance to define a future state vision in which the picking was made directly to the picking car and then the units had to be ready to send to the services without further need of arranging. The future state vision of the picking included, additionally, the organization of the picking list by location. The picking route was previously done without any standard route. With improvements to the system, the items appear by the order by which they should be picked.

In terms of Information systems, the improvements were clearly defined so they could be quickly incorporated into the GHAF. However, it needed to be complemented with a new picking infrastructure, namely, a picking car that could fit in the corridor and was appropriate to accommodate the picking of two orders at the same time. The solution designed is reported in Figures 4.8 and 4.9.

The idea is to have two boxes in the upper tray, one for each service to be picked, and have two additional boxes in case the service needs more than one. All the boxes have standard measures (600x400x320 mm) and are identified with the service to which they will go. With these improvements, one is expected to see the waste of movement reduced by at least 50%, as this waste is now shared by two services. The picking directly to the car is also expected to have a large impact on the picking time, and the inclusion of boxes will make the need for tidying in the end obsolete.

4.2.5 Daily Kaizen for basic stability

To some extent, the functions of the Pharmacy and of the Provisioning are similar, as in each of these areas there has to be picking and subsequent distribution of materials. Thus, some of the KPIs of the Daily Kaizen board of the Provisioning team (shown in Figure 4.10 might coincide with the ones of the Pharmacy. For this team, four KPIs were defined:

- Stock-outs: the daily number of units not supplied to the services
- Service level: the number of fulfilled lines divided by the total number of lines to be supplied

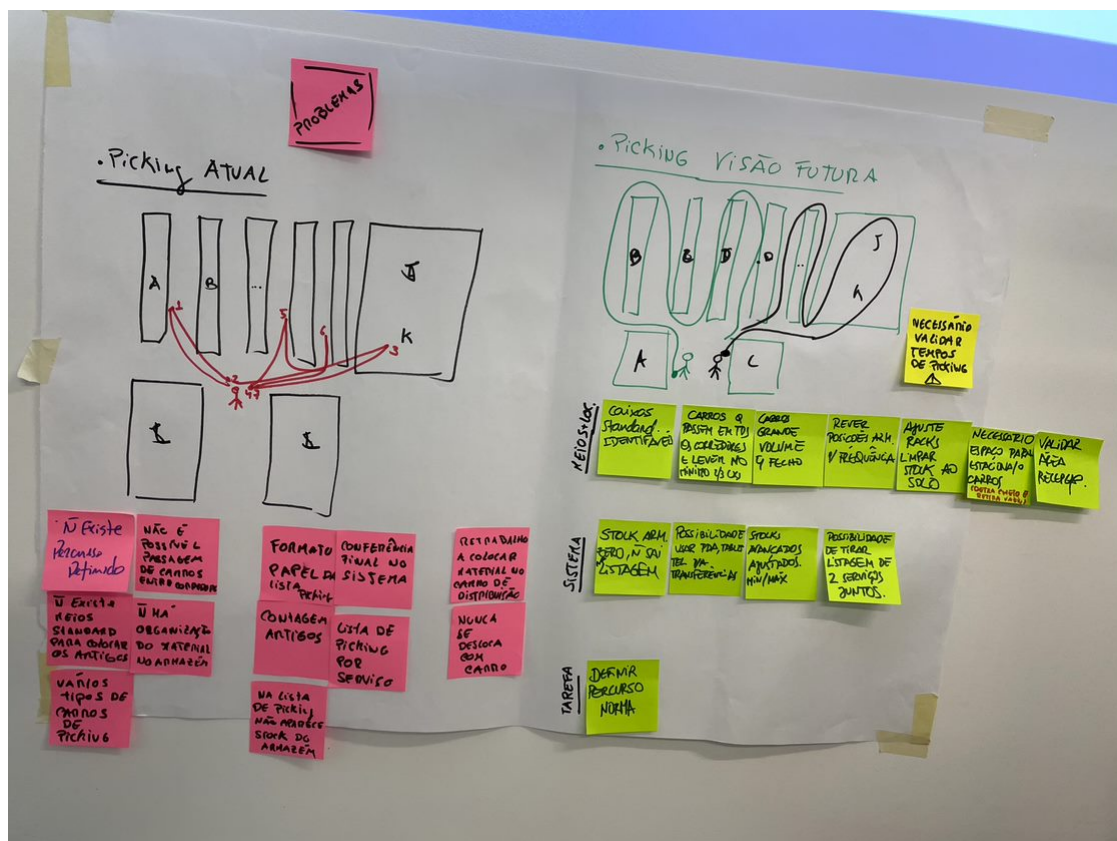


Figure 4.7: Picking - Current State and Future State

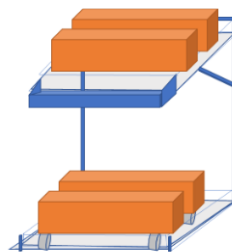


Figure 4.8: Picking car design

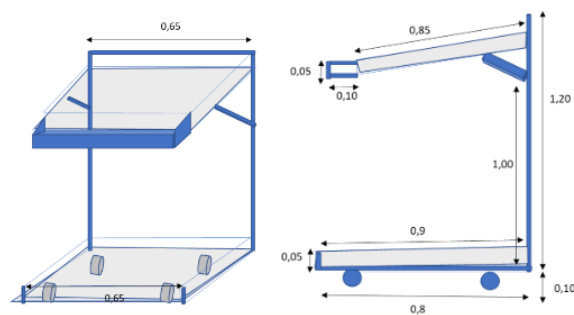


Figure 4.9: Picking car design with measures

- Productivity: number of lines fulfilled by an operator
- Errors and complaints: number of wrong references sent to the services and other complaints



Figure 4.10: Daily Kaizen Board of the Provisioning team

The other two templates seen in the Daily Kaizen board are the work map (*Mapa de Rotatividade*) and the count of causes that explain the Service level being below the target. The rest of the board elements are similar to the other boards, shown in the section 3.2.5.

4.2.6 5S in the warehouse of each service

This initiative had the goal of helping nurses of each service to find the material needed easier. In that sense, the actions in course in the warehouse of each service were:

- Screen what is needed and what is not, throw away obsolete items.
- Delimit the needed space for each reference with the new ROP and the new handling unit.
- Create a space for the Provisioning team to unload.

The result of this initiative in the Obstetrics service can be seen in Figures F.1 and F.2 of Appendix F.

Chapter 5

Supply system improvement opportunities

After acknowledging the need for internal development of teams and processes in the Pharmacy and the Provisioning, the supply system of these materials was analyzed, collecting information regarding the activities carried out to provide the services with the references from both of these support areas. Once again, the solution was designed aiming at reducing non-value-added activities, reducing average lead time by creating flow whenever possible, and reducing stock-outs. The solutions designed and implemented aim to answer the second Research Question posed in Chapter 1.

5.1 Current Situation Mapping

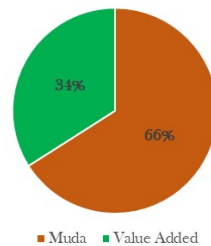
As seen in Chapter 3, the Pharmacy and the Provisioning teams are, among other roles, composed of members whose function consists solely of securing the transportation to the Services. The layout of the Hospital consists of the main building with eleven floors and four outside buildings (External Appointments I, II and III, and UMAD). This implies long waiting times for the lift and a lot of time wasted in transportation, which by definition does not add any value.

The route followed by the logistics operator for one service was followed and a *Muda*/VA Analysis was conducted. The results are presented in Figure 4.1.

Regardless of the movement being classified as *muda*, it is not possible to eliminate it completely. It is important to note that by the time the project began there was a dedicated team from both areas, meaning that the waste of movement was incurred two times for the same service. Also, there was not a clear distribution of the services such as the waste of space in the transportation cart was minimized. Taken this into account, the clear opportunity for improvement is the definition of a standardized route that secures the transportation of the two flows at the same time, daily, minimizing the waste of transportation as much as possible.

Task	Time (seconds)	Muda/VA	%
Provisioning	613	VA	34%
Movement	1187	Muda	66%

Current State Muda/VA Analysis

Figure 5.1: *Muda/VA* Analysis of the Supply System

More than this *Muda/VA* Analysis, to correctly design the future state, there was an observation of the time spent travelling to each service, specified for each one of the several tasks they perform and the type of movement (see Appendix D for the file of the time study).

5.2 Solution Principles

The opportunities for improvement were easily identified, and so was the solution principle to follow - to design and implement a *mizusumashi* route that would daily distribute medication and Provisioning material to the services of the Hospital. The implementation of this logistic train will, at least, reduce the waste of transportation by 50%. With an optimized route, the reduction is estimated to be even higher. Additionally, this will provoke a redundancy of function in the Pharmacy and in the Provisioning, allowing the Pharmacy or the Provisioning to liberate collaborators to other functions.

To implement this, there had to be a change of infrastructures. The new boxes of the Provisioning to do the Picking had to fit in the transportation car. To standardize the approach, the Pharmacy started making the picking to smaller boxes, as the medication occupies significantly less space than the Provisioning. The boxes chosen followed the European standard (see Figure 5.2).

The transportation car had to take into account several constraints: be able to be transported manually, fit into the Hospital lift and be able to accommodate the boxes dimensioned for the Provisioning and the Pharmacy. The result is schematized in Figure 5.3.

After defining the material needed, one needs to determine the best set of routes for the *mizusumashi* to follow daily, considering the time it takes to travel to each service, collected in

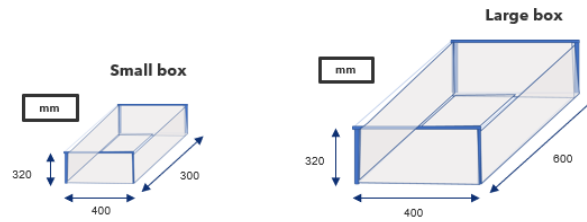


Figure 5.2: Dimension of the boxes for Pharmacy and Provisioning

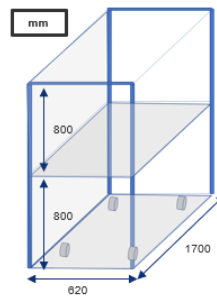


Figure 5.3: Dimensions of the transportation cars

the design phase, and the amount of material that needs to be provided. Regardless of the method followed to design the route, there are two clear goals to be attained:

- To minimize the distance travelled by the *mizusumashi*, to minimize the time spent in non-value adding activities.
- To maximize the space occupied in the transportation cart.

One way in which the route can be designed is resorting to exact methods, such as linear programming. If the solution space is wide, one can ponder to use approximate methods, such as heuristics. Both methods are presented in section 5.3 and later discussed in Chapter 6.

5.3 Optimization Model

5.3.1 Exact Methods

The challenge of the route design using exact methods lies in the formulation of the mathematical model. As any linear programming model, it must have an objective function, the definition of the inputs and decision variables, and a list of constraints. The mathematical formulation for this problem, given the context and the available data, would be the following:

Indexes:

$i = 1, 2, 3, \dots, I$ - services of the Hospital
 $j = 1, 2, 3, \dots, J$ - route number
 $k = 1, 2, 3, \dots, K$ - floors of the Hospital/locations

Inputs:

C_i , number of transportation carts needed for service i
 F_i , floor in which service i is situated
 n_{cars} , number of cars available

Auxiliary inputs:

$NServices_k$, number of services in floor k

Decision variables:

$X_{i,j}$, equals 1 if transportation for service i is in route j , equals 0 otherwise

Auxiliary decision variables:

R_j , equals 1 if route j is used, equals 0 otherwise

$P_{k,j}$, equals 1 if floor k is visited on route j , equals 0 otherwise

Objective function:

$$\min \sum_{j=1}^J R_j + \sum_{j=1}^K \sum_{k=1}^K R_j * P_{k,j} \quad (5.1)$$

Subject to:

$$P_{k,j} \geq \frac{\sum_{i=1}^I \sum_{j=1}^J X_{i,j} * R_j}{NServices_k}, \forall k \quad (5.2)$$

$$\sum_{j=1}^J R_j \geq \frac{\sum_{j=1}^N X_{i,j}}{I} \quad (5.3)$$

$$\sum_{j=1}^J X_{ij} = 1, \forall i \in I \quad (5.4)$$

$$\sum_{i=1}^I X_{i,j} * C_i \leq n_{cars}, \forall j \in J \quad (5.5)$$

$$P_{k,j} \leq 1, \forall k \in K, \forall j \in J \quad (5.6)$$

The equation 5.1 contains the objective function, a function of minimization that comprises a sum of two parcels. The first aims at attaining the second of the two goals defined: to maximize the space occupied in the transportation cart, which subsequently means minimizing the number of routes. The second part of the function is related to the other goal. If the second parcel is minimal, it means that one floor is not visited in many routes (ideally, only one). This forces the *mizusumahi* to always travel to the nearest service.

Equation 5.2 does the connection between auxiliary variable $P_{k,j}$ and decision variable $X_{i,j}$, stating that variable $P_{k,j}$ assumes the value of 1 if there is any service supplied in route j in floor k .

Equation 5.3 is responsible for doing the connection between auxiliary variable R_j and decision variable $X_{i,j}$, stating that this variable should be equal to 1 if the ratio between the sum of all services visited in route j divided by the number of services I is greater than zero.

Equation 5.4 allocates one service only to one route, as it states that the sum of all routes for any service should be equal to 1.

Equation 5.5 is responsible for not allowing the services transported in a given route to exceed the capacity provided by the number of cars.

This model was run using the Microsoft Excel Solver tool. Figure E.1 in Appendix E shows how the mathematical formulation was translated into the program. The running of the program is expected to retrieve the optimal solution for this problem.

5.3.2 Approximate Methods

Metaheuristics are a method to solve optimization problems that return "«acceptable» solutions in a reasonable time for solving hard and complex problems in science and engineering" (Talbi, 2009). Every metaheuristic has two steps: the constructive heuristic and the improvement heuristic. The first constructs an initial solution that previously the improvement heuristic will work on.

For this problem, the solution space corresponds to the way in which 35 services can be organized in a sequence of routes, which mathematically corresponds to $35! = 1.0333148^{40}$ possibilities for organizing the routes. This makes the problem a combinatorial one and suitable for using metaheuristics.

Metaheuristics are usually developed for problems that have already been studied. So before any implementation of a heuristic, one should search the literature for the type of problem that resembles the proposed problem the most. For the case of the problem posed in this chapter, the one that has the most in common with this problem is the VRP (Vehicle Routing Problem). In this case, this variation relates to a Capacitated VRP (CVRP), as the vehicle has limited capacity.

The design of the constructive heuristic for the CVRP follows the following logic: the vehicle starts at the depot (in this case, the central warehouse). Then, it travels to a random location. After that, the next location it goes to is determined by a dispatching rule, according to which the location that ranks the highest or the lowest (according to the objective function of the problem) is the next location to be visited. This continues until the capacity of the vehicle is reached and then the vehicle has to go back to the central warehouse to go to another route. This goes on until all the locations are visited. Problems of this nature are usually accompanied by time restrictions, but this is not the case.

Transposing this to the present problem, where the logistics team has 35 locations to visit, the capacity of transportation is 4 transportation cars, corresponding to approximately $6,75 m^3$. For every service, the approximate quantity to supply was estimated in terms of the number of boxes by the collaborators that daily distribute medication and Provisioning material. Also, it is known the distance in terms of floors, as most of the time spent in transportation is due to extensive waiting times for the lift.

The dispatching rule must take into consideration the two goals of the problem: to minimize the number of routes (maximize the volume transported in each car) and to minimize the distance travelled. The first goal can be taken into account in the constructive heuristic, as it will only close one route if any other service does not fit or is too far away. The other goal can be embedded in the dispatching rule and can be formulated as stated in equation 5.7. The weight of the service depends on the distance between service i and j . Candidate services will be ordered in ascending order and the first one will be chosen to go next. When the capacity corresponding to the number of cars is reached, the *mizusumashi* should end the route and go back to the central warehouse to perform the next route, which will be calculated similarly to the first. When all services are allocated to a route, the algorithm must stop and retrieve the number of routes, the services in each route, the volume of air transported as the number of cars and the distance travelled in terms of the number of floors. The next step is defining the constructive heuristic so that one is capable to have an initial solution to work on. The pseudo-code for this constructive heuristic can be seen in Algorithm 1.

$$w(i, j) = d_{ij} \quad (5.7)$$

Result: InitialSolution

InitialSolution = $\emptyset$;

```

while aux < NumServices do
    i  $\leftarrow$  Random (0;NServices);
    if i NOT IN InitialSolution then
        i  $\leftarrow$  InitialLocation ;
        Route  $\leftarrow$  Route  $\cup$  i ;
        VolRoute  $\leftarrow$  Vol(i);
        aux  $\leftarrow$  aux + 1
    else
        | Exit While
    end
    while FullCar is FALSE do
        Initialize the Candidate List;
        for j  $\leftarrow$  1 to NServices do
            Add j to CandidateList;
            Calculate w(i, j);
        end
        for k  $\leftarrow$  1 to len(Route) do
            Remove Route(k) from CandidateList;
        end
        Order CandidateList by ascending order of w(i, j);
        Select h, the first candidate of CandidateList;
        if VolRoute + Vol(h) < Ncars*Volume then
            Route  $\leftarrow$  Route  $\cup$  h;
            VolRoute  $\leftarrow$  VolRoute  $\cup$  Vol(h);
            i  $\leftarrow$  h;
            aux  $\leftarrow$  aux + 1
        else
            if CandidateList  $\neq \emptyset$  then
                | Remove h from CandidateList
            else
                Route  $\leftarrow$  Route  $\cup$  CentralWarehouse;
                InitialSolution  $\leftarrow$  InitialSolution  $\cup$  Route;
                Route  $\leftarrow \emptyset$ ;
                FullCar  $\leftarrow$  TRUE
            end
        end
    end
end

```

Algorithm 1: Constructive Heuristic Pseudocode

The next step to improve the initial solution is to define the evaluation criteria which will dictate how close the solution is to an optimal solution, according to the goals defined. The Evaluation Function can be formulated as seen in Equation 5.8. The first part of the equation corresponds to the goal of maximizing the volume transported, so the first parcel is the average of air transported in each route. The second parcel guarantees that the distance travelled is minimal by summing the distance in all routes. As in Linear Programming, R_j is a binary variable that equals 1 if route j is used, V_j is the cumulative volume of each route j , and D_j is the cumulative distance travelled in each route j .

$$EvaluationFunction = \sum_{j=1}^J R_j * (n_{cars} - V_j) / \sum_{j=1}^J R_j + \sum_{j=1}^J D_j \quad (5.8)$$

To make sure that the values do not have different orders of magnitude, it is necessary to normalize the values, according to the formula 5.9.

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (5.9)$$

The volume of air as the number of cars ranges between 0 and 4. The distance travelled ranges between 8 and 647, corresponding to the best and worst-case scenario in terms of the number of floors travelled for each service, and summing those values for all the services.

Commonly, the next step is to define one or more moves that will generate neighbours of the initial solution (solutions that only differ from the initial solution in a given number of positions). In the present case, the approach has to be different, as swapping a given service in a route or swapping a service between different routes does not add much value in terms of time spent in transportation or occupation of the transportation cart. Thus, the approach followed consisted of running the Constructive Heuristic a finite number of times from different initial random locations, in order to find a solution better than the initial one, i.e., one that has a lower value of the Evaluation Function. The pseudocode for the approach followed is summarized in Algorithm 2.

```

Inputs: InitialSolution ;
Result: BestSolution
InitialSolution  $\leftarrow$  Constructive();
BestValue  $\leftarrow$  Evaluation(InitialSolution);
while  $i \leq \text{MaxNoIterations}$  do
    | Iteration  $\leftarrow$  Constructive();
    | ValueIteration  $\leftarrow$  Evaluation(Iteration);
    | if  $\text{ValueIteration} \leq \text{BestValue}$  then
    | | BestSolution  $\leftarrow$  Solution;
    | | BestValue  $\leftarrow$  ValueIteration;
    | |  $i \leftarrow i + 1$ ;
    | end
end

```

Algorithm 2: Improvement Pseudocode

The results of the Constructive and Improvement algorithms can be found in Chapter 6, alongside the comparison between this method and Linear Programming.

Chapter 6

Results

This chapter aims at presenting the results attained with some initiatives described in the previous chapters. Whilst the measuring of the impact in quantitative terms disregards the effect of the actions in terms of cultural environment and work method in the teams, it is of paramount importance to measure the KPIs throughout the process to validate the solutions implemented. The quantitative results of two of the most important initiatives implemented are reported in Sections 6.1 and 6.2. A brief note on the qualitative repercussions of the project is shown in Section 6.3.

6.1 Multi-order picking

The VSM phase of the project showed that the current situation regarding the picking had room for improvement. The time was taken for the separate preparation of two services, UCA and Cardiology, separately. Implementing multi-order picking, with the new picking cart and picking for boxes, plenty of time was saved, as Figure 6.1 shows: before multi-order picking, the picking for these two services took 1787 seconds (approximately 28 minutes). After multi-order picking implementation, the time was reduced by 43%, for 1020 seconds (17 minutes). Depending on the similarity of references between services, this reduction is expected to drastically reduce the picking time for all services. Additionally, at least one picker can be allocated to other tasks after the implementation of multi-order picking.

6.2 Pharmacy and Provision flow integration

Regarding the *mizusumashi* routing using exact and approximate methods, it is important to notice that the times to travel to each service were obtained by direct observation of the daily deliveries to the services before the implementation of the routes and the flow integration. The file for the Time Study can be found in Appendix D. The time spent on transportation before the implementation of the routes was approximately 458 minutes in total, considering Pharmacy and Provisioning doing the transportation separately. The results obtained with the Linear Programming model executed using Microsoft Excel Solver are reported in Figure 6.2. **Note:** The distance

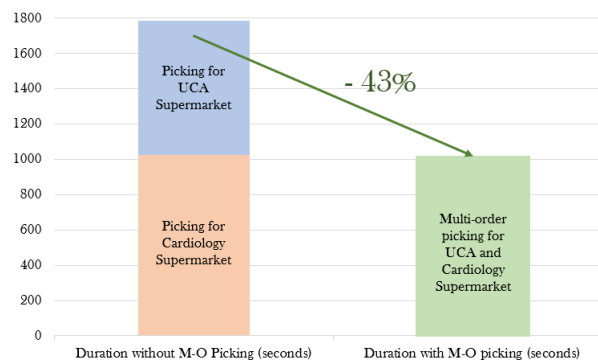


Figure 6.1: Multi-order picking results

shown in Figure 6.2 is a relative distance calculated as the number of floors between each service. When the building is not the same, the distance was converted into the number of floors.

Route	Services								Time	Distance	Air	
Route 1	Esterilização	Neonatologia	Pediatria	Ortopedia Homens	Ortopedia Mulheres	Cardiologia	Urologia/ Cirurgia 7		18:15:16	4	0,33	
Route 2	Bloco/Anestesia	Observações	Urgência	Cirurgia	Internamento I	Neuro/Pneumo			14:38:22	9	0,23	
Route 3	Bloco P5	Ginecologia	Obstetrícia A	Obstetrícia B	Medicina 9	Medicina 10			61:58:16	5	0,75	
Route 4	Imagiologia	Paliativos	UCIP	UDIC	Urgência	Urgência Pediatria			65:32:13	0	1,03	
Route 5	Hospital de Dia	Anestesia-Dor	Psiquiatria	Administrativo	Consulta Externa III	UCA	HD Gastro	HD Oncologia	UMAD	39:11:40	19	1,68
									199:35:47	37	4,02	

Figure 6.2: Linear Programming results

As for the results using the Approximate methods in Chapter 5, the Algorithm was implemented using Python and it was defined a maximum number of iterations of 20. The best result retrieved, according to the Evaluation function, is worse than the Linear Programming (Figure 6.3). To see how the results converged to the best solution in 20 iterations, the results were recorded into an Excel file. The results are reported in Figure G.1 of Appendix G. An example of a Python output for a solution is reported in Figure G.2.

One can conclude that the routes obtained with the Linear Programming model generate less waste than those obtained with the metaheuristic. Therefore, the routes chosen to perform should be the ones reported in Figure 6.2. The total number of minutes needed to perform the five routes obtained is 199 minutes, which corresponds to a reduction of about 56,5% (Figure 6.4). By the time these results were obtained, the conditions to implement were not reunited, so this figure was estimated via direct observation of the current state.

	Linear Programming		9th Iteration	
	Distance	Air	Distance	Air
Route 1	4	0,33	4	0,07
Route 2	9	0,23	28	0,28
Route 3	5	0,75	4	1,03
Route 4	0	1,03	7	1,28
Route 5	19	1,68	0	1,29
Sum/ Average	37	0,804	43	0,79
Normalized	0,05	0,20	0,05	0,20
Evaluation Function	0,246		0,252	

Figure 6.3: Comparison of results between exact and approximate methods

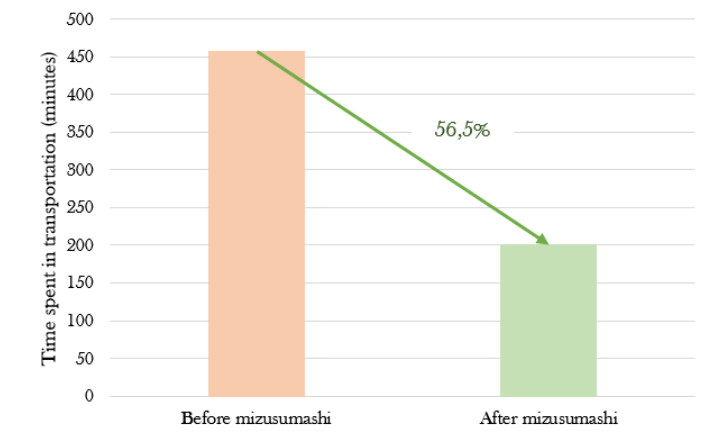


Figure 6.4: Graph of Linear Programming results

6.3 Other results

It is important to note that the result of a given solution depends directly on the effort and how firmly people believe in its impact. The percussion of bringing people together to think about solutions to improve their work, to give them space to complain about current problems and conditions, is not easily measurable in quantitative terms. However, it is one of the most important results of these initiatives. Having a Daily Kaizen routine to check the performance of each Team regularly and allowing everyone to suggest improvements to the current situation fosters the strive for operational excellence among the team members. Moreover, many of the people involved, due to the chronic verticality of organizations, did not have the opportunity to speak up about their problems. Kaizen and Lean methodologies such as the ones implemented in this project empower collaborators, makes them own the solutions and the implementation, and gives them all the tools that are needed to be the best - or, at least, better than yesterday, and hopefully worse than tomorrow.

Chapter 7

Conclusions and future work

This chapter encloses the answer to the Research Questions posed in Chapter 1, in Section 7.1. After that, a vision of the future of internal Logistics at the Hospital Senhora da Oliveira is presented in Section 7.2. The Chapter closes with a vision of the long-term future and how will global trends impact Hospital internal Logistics (Section 7.3).

7.1 Conclusions

The chance to implement some of the initiatives proposed throughout Chapter 3 and 4 helped to answer the two research questions posed in the beginning.

RQ1: What are the improvement opportunities possible to identify and approach in the Pharmacy and Provisioning, both internally and in the interactions with the services of the Hospital?

The VSM tool has revealed to be extremely efficient in analyzing the current situation and grasping the problems within the areas chosen. The solution principles, designed in light of Kaizen/Lean methods and beliefs, were efficient in providing results rapidly. Some of the improvement opportunities were common between the two areas and essentially related to lack of coordination between the team, lack of standardized processes, non-optimized layouts and the performing of a great number of non-value-added tasks. As Lean sees the world as a mix of value-added and waste, the solutions are all oriented to waste reduction or elimination and are effective in doing so.

A key issue inherent to all Lean and Kaizen applications is resistance to change. In a Hospital, the strain is even harder, as collaborators are not properly efficiency-oriented and do not see the value of Lean as quickly as collaborators with an industrial background. Thus, as people are the ignition of change, the initiatives are prone to failure when nurses and doctors do not firmly believe in the concepts, which is the most important duty of consultants in this type of projects.

RQ2: Would it be efficient to integrate the Pharmacy flow and the Provisioning flow in the same supply system? If so, how can the route travelled by the logistic train be optimized?

The answer is straightforward after looking at the results. The integration of the two flows is highly beneficial for productivity. Unifying the supplies of clinical consumables and medication is expected to reduce by slightly more than half the time spent in transportation.

Regarding the optimization of this route, it became clear that both methods tested contributed to this reduction of time, with the Linear Programming being the one that presented better results. The adoption of a metaheuristic also resulted in a lower transportation time but the occupation of the transportation cars was not fully maximized, and neither the distance travelled was reduced to a minimum.

These results can be transposed to any problem of this kind as it is clear that having an integrated internal Logistics supply system is a step towards the vision of a Hospital with zero-waste.

On the whole, the Hospital's internal Logistic system benefited from the implementation of the *mizusumashi* route, saving resources and time. The supermarket implementation greatly reduced the time nurses spent in logistic operations and liberated time for them to treat patients. All the improvements made in each of the teams will also improve internal operations and allow the teams to better serve the services' needs.

7.2 Further developments

Immediate work to be developed consist of the improvement of the Linear Programming algorithm to evolve dynamically over time. The routes must not be static and should change according to the volume to be transported to each service each day.

Additionally, since the Approximate method developed was close to the Linear Programming model in terms of the Evaluation Function, there should be a test of the weight attributed to each goal in order to develop this model. The coefficients to attribute to each parcel of the Evaluation Function should be fine-tuned using Design of Experiments. Moreover, other diversification methods should be explored. Mingozi (2005) states that Tabu Search is the most efficient heuristic to solve a CVRP, the one that resembles the Hospital routing problem the most.

The next step to be implemented in this Hospital relates to a trend in Hospital internal Logistics that has great potential. By the classical definition of value, which is the foundation of Lean and Kaizen, a nurse adds value when he or she is taking care of a patient. Considering that, every time they are counting medication, placing orders to the warehouse or scanning an item, is an amount of time they are not treating a patient in need. In the near future, it is advisable for the Hospital to remove this responsibility from the nurses and the Logistics team takes over to assume this

function. In HSOL, the challenge lies in allocating the small Provisioning team to all the tasks that need to be performed.

However, the way for liberating nurses from logistic tasks is clear: the Provisioning team would be responsible not only for distributing the medication and the clinical consumables but also for arranging the items on the shelves, without the need for hiring skilled labour that actually know what the items are for. Ideally, the nurses do not touch the computer, nor they use the scanner to register the consumption of a given material. This can be achieved by following the model described in Figure 7.1.

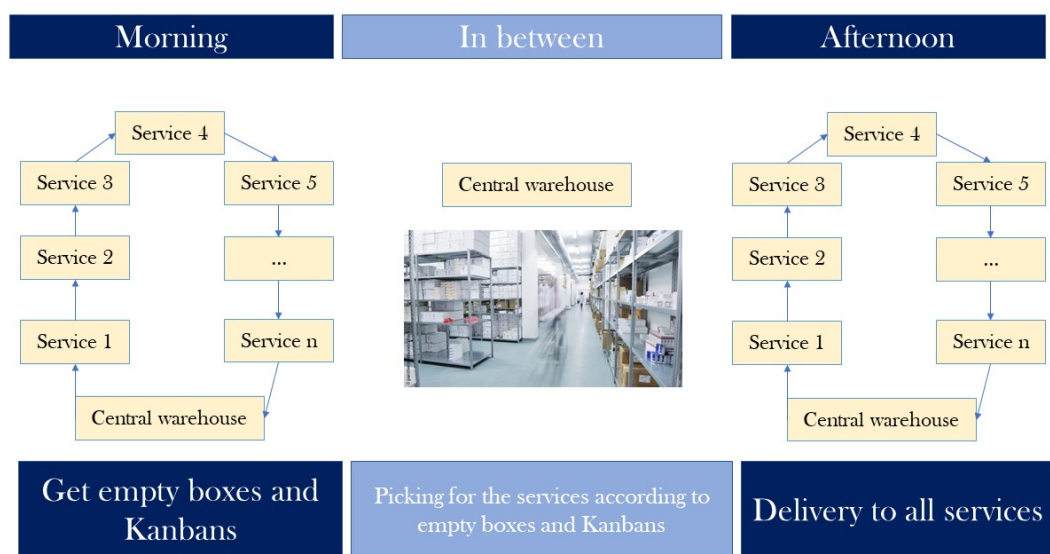


Figure 7.1: Future Internal Logistic system

The day starts with getting empty boxes and Kanbans from the warehouses of each service. The empty boxes are also a Kanban, as they are a visual mean of signalling the need for replenishment. Every service must have either one of these methods: double box or Kanban. After getting everything from all the services, the Provisioning team starts filling the empty boxes or replenishing to a box everything that has a Kanban associated. When everything is ready to send for the services, the *mizusumashi* has to start delivering. It is advisable that routes are made in parallel with other routes. In every service, the collaborator that delivers also arranges the items on the shelves. This is made using a code of the location where the items should be placed, as in that way it there is no need for skilled labour. An example of this application can be seen in Figure 7.2.

Undoubtedly, this is the way to have an internal logistics system completely oriented to the value of each collaborator. The difficulties of implementing this vision relate to the resizing and re-definition of functions of the Provisioning and Pharmacy team and changes to the information system.



Figure 7.2: Items by location to ease the arranging of materials

7.3 The long-distant future of Hospital internal Logistics

How can the vision in the previous Section be further improved? There will come a time when the answer will be unanimous: "Robots". For the majority of Hospitals in Portugal, that time is not close. However, worldwide, there are already reported successful applications of technologies such as AGV (Automatic Guided Robots) or even Automated Medication Dispensers. What these devices aim to do is, besides providing time for nurses to take care of the patients, to eliminate the need for a workforce in Logistics.

Regarding AGV, the work of Pedan et al. (2017) describes the guidelines for implementing and the benefits that are possible to get from AGV in a Hospital. An existing AGV device for a Hospital can be seen in Figure 7.3

According to the author, taking into consideration all flows of transportation within a Hospital (Laundry and meals), it is possible to achieve a reduction of 345 minutes of human labour. The same article estimates the investment associated with the purchasing and installing of AGV of 115,700€. Another reported success case study is the one reported in the work of Benzidia et al. (2019), in which the feedback of the implementation confirms how oriented to the value-added of the nurses this solution is:



Figure 7.3: Hospital AGV

"We have been able to provide the nursing staff the time needed by giving them to focus solely on patients and manage their tasks services. As you know, in many cases, patients need a real proximity to nursing staff; they have a big medico-psychological role that needs to be protected."

Furthermore, the counting of medication and even the scanning of the barcode when the nurse uses an item will be completely obsolete when Hospitals start having Autonomous Pharmacy devices and technology. An example of these devices is the ones offered by Omnicell. These devices are reported to reduce by 54% nurse medication retrieval time, to save 72% of nurse time and 80.8% of pharmacist time.¹ An example of an Omnicell pharmaceutical retriever can be seen in Figure 7.4.



Figure 7.4: Hospital AGV

These are some solutions that are likely to be implemented in Healthcare in the long-distant future in Portugal. The technological development allied with a clear notion of what is Value

¹Source: Omnicell website, <https://www.omnicell.com/point-of-care>

Added and *Muda* will contribute positively to make the full transition from Healthcare to Lean Healthcare.

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Appendix A

Scheduling of reception and storage

ESCALA RECEÇÃO/ ARRUMAÇÃO				
				
Mês				
	Sem____	Sem____	Sem____	Sem____
Técnico				
Assistente Operacional				
Administrativo				

Figure A.1: Standard scheduling of reception and storage

Appendix B

KPIs of the Production Daily Kaizen board

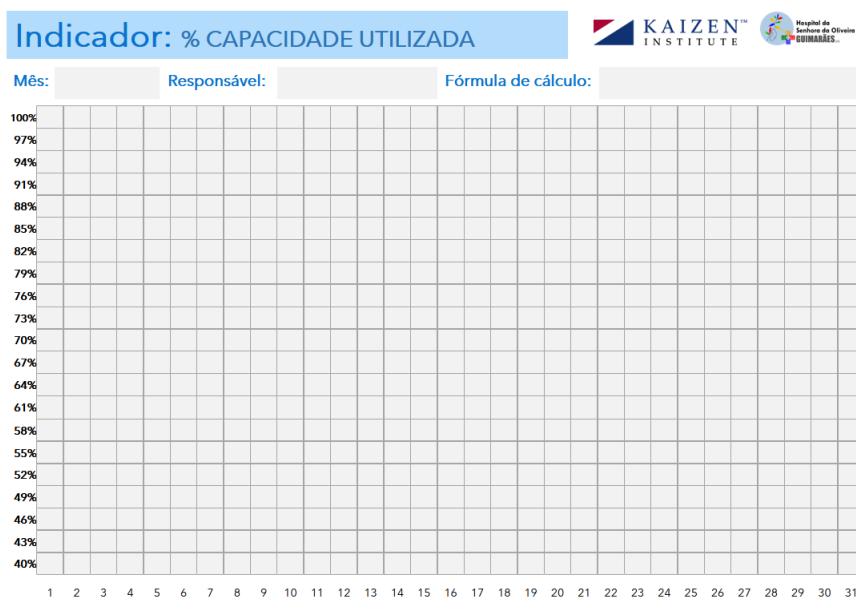


Figure B.1: Used capacity of Production

CUMPRIMENTO TAREFAS			KAIZEN [™] INSTITUTE	Hospital de São José do Rio Preto HOSPITAL
TAREFAS	JANELA HORÁRIA	REAL		
DÉBITOS	[- 14:30h]			
RÓTULOS	[- 14:30h]			
ARRUMAÇÃO DE MATERIAL CLÍNICO	apenas executar			
ARRUMAÇÃO DE MEDICAMENTOS	apenas executar			
SEPARAÇÃO DE MEDICAMENTOS	apenas executar			
PREPARAÇÃO DE MATERIAL CLÍNICO	apenas executar			
ENTREGA DE MEDICAÇÃO SEM NECESSIDADE DE PREPARAÇÃO	dia anterior			
REGISTO DE LOTES	[- 09:00h]			
LIMPEZA DIÁRIA	[- 17:00h]			
LIMPEZA SEMANAL	[- 17:00h]			

Figure B.2: Daily tasks fulfilled

CUMPRIMENTO HORÁRIOS										KAIZEN [™] INSTITUTE	Hospital de São José do Rio Preto HOSPITAL
# DOENTE	JANELA ENVIO PROCESSO	REAL	JANELA OK MANHÃ	REAL	TEMPO PREPARAÇÃO 1ª MEDICAÇÃO OBJ MANHÃ	REAL	JANELA OK TARDE	REAL	TEMPO PREPARAÇÃO 1ª MEDICAÇÃO OBJ TARDE	REAL	
1	Dia 0 [- 13h]		[08:30-09:00h]		01:00h		[14-15:30h]		01:00h		
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

Figure B.3: Schedules fulfilled

Periodical review of the Reorder Points for each reference

Atenção: A diferença do ponto de encorrenda sugerido pode ser grande devido à unidade de débito definida em sistema.

Figure C.1: Excel file for reviewing the ROP for each reference

Appendix D

File for time study of the Supply System

FARMÁCIA												
Destino	Edifício	Piso	Destacar do Serviço ant Elevador	Espora Elevador	Destacar Elevador	Destacar ant arrumação avançado	Espora Arrumação Avançada	Abastecer	Destacar ant Elevador	Espora Elevador	Destacar Elevador	Destacar do Serviço ant Serviço
Bloco Operatório + Anestesiologia (A)		2	0:17	0:09	0:18	0:53	0:00	0:05	1:32	0:03	0:16	0:18
Paliativos		2	0:46	0:46	0:32	1:06	0:00	2:05	1:01	0:46	0:21	0:18
CBS		2	0:46	0:46	0:32	1:06	0:00	2:05	1:01	0:46	0:21	0:18
UICP (A)		2	0:17	0:09	0:18	1:34	0:00	3:53	0:41	0:03	0:16	0:18
UDIC		2	0:46	0:46	0:32	1:06	0:00	2:05	1:01	0:46	0:21	0:18
Imagiologia		2	0:46	0:46	0:32	1:06	0:00	2:05	1:01	0:46	0:21	0:18
Uro-Pediatrica		2										00:00:00
Urgência (A)		2	0:13	0:06	0:23	1:01	0:00	2:19	0:50	0:40	0:20	0:12
Bloco PS		5	1:12	0:46	0:28	0:59	0:00	0:33	0:50	0:46	0:28	1:12
												07:17:03

Figure D.1: Excel file for registering the time of the supply of Provisioning and Pharmacy for each service of the Hospital

Appendix E

File for determining the best route using Linear Programming

Solver Parameters

Set Objective: 

To: ☐ Max ☒ Min ☐ Value Of:

By Changing Variable Cells: 

Subject to the Constraints:

\$H\$31:\$V\$39 <= 1

\$H\$31:\$V\$39 = binary

\$H\$31:\$V\$39 >= \$H\$42:\$V\$50

\$H\$4:\$V\$4 <= 1

\$H\$4:\$V\$4 = binary

\$H\$4:\$V\$4 >= \$H\$5:\$V\$5

\$H\$7:\$V\$29 = binary

\$W\$7:\$W\$29 = 1

\$Y\$5:\$AM\$5 <= 4

Add

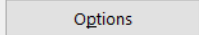
Change

Delete

Reset All

Load/Save

☒ Make Unconstrained Variables Non-Negative

Select a Solving Method:  

Solving Method
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

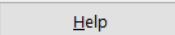
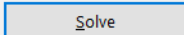
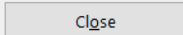
  

Figure E.1: Solver dialog box for the Linear Programming

Appendix F

Results of the 5S Campaign in the Obstetrics service

BEFORE



AFTER



Figure F.1: Results of the 5S campaign in Obstetrics - delimiting space

BEFORE



AFTER



Figure F.2: Results of the 5S campaign in Obstetrics - Unload zone

Mizusumashi route using approximate methods

ROTA	Prog Lin	Corrida 1	Corrida 2	Corrida 3	Corrida 4	Corrida 5	Corrida 6	Corrida 7	Corrida 8	Corrida 9
1	4	0.33	4	0.07	5	0.28	6	0.33	4	0.07
2	5	0.32	5	0.48	6	0.38	7	0.39	5	0.39
3	6	0.33	6	0.48	7	0.22	8	0.34	6	0.34
4	7	0.33	7	0.48	8	0.22	9	0.34	7	0.34
5	8	0.33	8	0.48	9	0.22	10	0.34	8	0.34
6	9	0.33	9	0.48	10	0.22	11	0.34	9	0.34
7	10	0.33	10	0.48	11	0.22	12	0.34	10	0.34
8	11	0.33	11	0.48	12	0.22	13	0.34	11	0.34
9	12	0.33	12	0.48	13	0.22	14	0.34	12	0.34
10	13	0.33	13	0.48	14	0.22	15	0.34	13	0.34
11	14	0.33	14	0.48	15	0.22	16	0.34	14	0.34
12	15	0.33	15	0.48	16	0.22	17	0.34	15	0.34
13	16	0.33	16	0.48	17	0.22	18	0.34	16	0.34
14	17	0.33	17	0.48	18	0.22	19	0.34	17	0.34
15	18	0.33	18	0.48	19	0.22	20	0.34	18	0.34
16	19	0.33	19	0.48	20	0.22	21	0.34	19	0.34
17	20	0.33	20	0.48	21	0.22	22	0.34	20	0.34
18	21	0.33	21	0.48	22	0.22	23	0.34	21	0.34
19	22	0.33	22	0.48	23	0.22	24	0.34	22	0.34
20	23	0.33	23	0.48	24	0.22	25	0.34	23	0.34
21	24	0.33	24	0.48	25	0.22	26	0.34	24	0.34
22	25	0.33	25	0.48	26	0.22	27	0.34	25	0.34
23	26	0.33	26	0.48	27	0.22	28	0.34	26	0.34
24	27	0.33	27	0.48	28	0.22	29	0.34	27	0.34
25	28	0.33	28	0.48	29	0.22	30	0.34	28	0.34
26	29	0.33	29	0.48	30	0.22	31	0.34	29	0.34
27	30	0.33	30	0.48	31	0.22	32	0.34	30	0.34
28	31	0.33	31	0.48	32	0.22	33	0.34	31	0.34
29	32	0.33	32	0.48	33	0.22	34	0.34	32	0.34
30	33	0.33	33	0.48	34	0.22	35	0.34	33	0.34
31	34	0.33	34	0.48	35	0.22	36	0.34	34	0.34
32	35	0.33	35	0.48	36	0.22	37	0.34	35	0.34
33	36	0.33	36	0.48	37	0.22	38	0.34	36	0.34
34	37	0.33	37	0.48	38	0.22	39	0.34	37	0.34
35	38	0.33	38	0.48	39	0.22	40	0.34	38	0.34
36	39	0.33	39	0.48	40	0.22	41	0.34	39	0.34
37	40	0.33	40	0.48	41	0.22	42	0.34	40	0.34
38	41	0.33	41	0.48	42	0.22	43	0.34	41	0.34
39	42	0.33	42	0.48	43	0.22	44	0.34	42	0.34
40	43	0.33	43	0.48	44	0.22	45	0.34	43	0.34
41	44	0.33	44	0.48	45	0.22	46	0.34	44	0.34
42	45	0.33	45	0.48	46	0.22	47	0.34	45	0.34
43	46	0.33	46	0.48	47	0.22	48	0.34	46	0.34
44	47	0.33	47	0.48	48	0.22	49	0.34	47	0.34
45	48	0.33	48	0.48	49	0.22	50	0.34	48	0.34
46	49	0.33	49	0.48	50	0.22	51	0.34	49	0.34
47	50	0.33	50	0.48	51	0.22	52	0.34	50	0.34
48	51	0.33	51	0.48	52	0.22	53	0.34	51	0.34
49	52	0.33	52	0.48	53	0.22	54	0.34	52	0.34
50	53	0.33	53	0.48	54	0.22	55	0.34	53	0.34
51	54	0.33	54	0.48	55	0.22	56	0.34	54	0.34
52	55	0.33	55	0.48	56	0.22	57	0.34	55	0.34
53	56	0.33	56	0.48	57	0.22	58	0.34	56	0.34
54	57	0.33	57	0.48	58	0.22	59	0.34	57	0.34
55	58	0.33	58	0.48	59	0.22	60	0.34	58	0.34
56	59	0.33	59	0.48	60	0.22	61	0.34	59	0.34
57	60	0.33	60	0.48	61	0.22	62	0.34	60	0.34
58	61	0.33	61	0.48	62	0.22	63	0.34	61	0.34
59	62	0.33	62	0.48	63	0.22	64	0.34	62	0.34
60	63	0.33	63	0.48	64	0.22	65	0.34	63	0.34
61	64	0.33	64	0.48	65	0.22	66	0.34	64	0.34
62	65	0.33	65	0.48	66	0.22	67	0.34	65	0.34
63	66	0.33	66	0.48	67	0.22	68	0.34	66	0.34
64	67	0.33	67	0.48	68	0.22	69	0.34	67	0.34
65	68	0.33	68	0.48	69	0.22	70	0.34	68	0.34
66	69	0.33	69	0.48	70	0.22	71	0.34	69	0.34
67	70	0.33	70	0.48	71	0.22	72	0.34	70	0.34
68	71	0.33	71	0.48	72	0.22	73	0.34	71	0.34
69	72	0.33	72	0.48	73	0.22	74	0.34	72	0.34
70	73	0.33	73	0.48	74	0.22	75	0.34	73	0.34
71	74	0.33	74	0.48	75	0.22	76	0.34	74	0.34
72	75	0.33	75	0.48	76	0.22	77	0.34	75	0.34
73	76	0.33	76	0.48	77	0.22	78	0.34	76	0.34
74	77	0.33	77	0.48	78	0.22	79	0.34	77	0.34
75	78	0.33	78	0.48	79	0.22	80	0.34	78	0.34
76	79	0.33	79	0.48	80	0.22	81	0.34	79	0.34
77	80	0.33	80	0.48	81	0.22	82	0.34	80	0.34
78	81	0.33	81	0.48	82	0.22	83	0.34	81	0.34
79	82	0.33	82	0.48	83	0.22	84	0.34	82	0.34
80	83	0.33	83	0.48	84	0.22	85	0.34	83	0.34
81	84	0.33	84	0.48	85	0.22	86	0.34	84	0.34
82	85	0.33	85	0.48	86	0.22	87	0.34	85	0.34
83	86	0.33	86	0.48	87	0.22	88	0.34	86	0.34
84	87	0.33	87	0.48	88	0.22	89	0.34	87	0.34
85	88	0.33	88	0.48	89	0.22	90	0.34	88	0.34
86	89	0.33	89	0.48	90	0.22	91	0.34	89	0.34
87	90	0.33	90	0.48	91	0.22	92	0.34	90	0.34
88	91	0.33	91	0.48	92	0.22	93	0.34	91	0.34
89	92	0.33	92	0.48	93	0.22	94	0.34	92	0.34
90	93	0.33	93	0.48	94	0.22	95	0.34	93	0.34
91	94	0.33	94	0.48	95	0.22	96	0.34	94	0.34
92	95	0.33	95	0.48	96	0.22	97	0.34	95	0.34
93	96	0.33	96	0.48	97	0.22	98	0.34	96	0.34
94	97	0.33	97	0.48	98	0.22	99	0.34	97	0.34
95	98	0.33	98	0.48	99	0.22	100	0.34	98	0.34
96	99	0.33	99	0.48	100	0.22	101	0.34	99	0.34
97	100	0.33	100	0.48	101	0.22	102	0.34	100	0.34
98	101	0.33	101	0.48	102	0.22	103	0.34	101	0.34
99	102	0.33	102	0.48	103	0.22	104	0.34	102	0.34
100	103	0.33	103	0.48	104	0.22	105	0.34	103	0.34
101	104	0.33	104	0.48	105	0.22	106	0.34	104	0.34
102	105	0.33	105	0.48	106	0.22	107	0.34	105	0.34
103	106	0.33	106	0.48	107	0.22	108	0.34	106	0.34
104	107	0.33	107	0.48	108	0.22	109	0.34	107	0.34
105	108	0.33	108	0.48	109	0.22	110	0.34	108	0.34
106	109	0.33	109	0.48	110	0.22	111	0.34	109	0.34
107	110	0.33	110	0.48	111	0.22	112	0.34	110	0.34
108	111	0.33	111	0.48	112	0.22	113	0.34	111	0.34
109	112	0.33	112	0.48	113	0.22	114	0.34	112	0.34
110	113	0.33	113	0.48	114	0.22	115	0.34	113	0.34
111	114	0.33	114	0.48	115	0.22	116	0.34	114	0.34
112	115	0.33	115	0.48	116	0.22	117	0.34	115	0.34
113	116	0.33	116	0.48	117	0.22	118	0.34	116	0.34
114	117	0.33	117	0.48	118	0.22	119	0.34	117	0.34
115	118	0.33	118	0.48	119	0.22	120	0.34	118	0.34
116	119	0.33	119	0.48	120	0.22	121	0.34	119	0.34
117	120	0.33	120	0.48	121	0.22	122	0.34	120	0.34
118	121	0.33	121	0.48	122	0.22	123	0.34	121	0.34
119	122	0.33	122	0.48	123	0.22	124	0.34	122	0.34
120	123	0.33	123	0.48	124	0.22	125	0.34	123	0.34
121	124	0.33	124	0.48	125	0.22	126	0.34	124	0.34
122	125	0.33	125	0.48	126	0.22	127	0.34	125	0.34
123	126	0.33	126	0.48	127	0.22	128	0.34	126	0.34
124	127	0.33	127	0.48	128	0.22	129	0.34	127	0.34
125	128	0.33	128	0.48	129	0.22	130	0.34	128	0.34
126	129	0.33	129	0.48	130	0.22	131	0.34	129	0.34
127	130	0.33	130	0.48	131	0.22	132	0.34	130	0.34
128	131	0.33	131	0.48	132	0.22	133	0.34	131	0.34
129	132	0.33	132	0.48	133	0.22	134	0.34	132	0.34
130	133	0.33	133	0.48	134	0.22	135	0.34	133	0.34
131	134	0.33	134	0.48	135	0.22	136	0.34	134	0.34
132	135	0.33	135	0.48	136	0.22	137	0.34	135	0.34
133	136	0.33	136	0.48	137	0.22	138	0.34	13	

Figure G.1: Results of Linear Programming compared with 20 iterations of the Constructive Heuristic

```
['Recobro Tardio' 'MFR' 'Administrativo' 'Hospital de Dia' 'Anestesia-Dor'  
'Psiquiatria' 'Administrativo' 'Consulta Externa 3' 'HD Oncologia' 'UCA'  
'HD Gastro' 'UMAD' 'Paliativos' 'Urgência Pediatria' 'Observações' 'UDIC'  
'Imagiologia' 'Bloco P5' 'Obstetrícia']  
3.7264957264957266 32  
  
['Medicina Interna 9' 'Cardiologia/UCIC' 'Urologia/Cirurgia 7'|  
'Ortopedia Homens' 'Ortopedia Mulheres' 'Ginecologia'] |  
3.692307692307693 4|  
  
['Neonatologia/UCIN' 'Pediatria' 'Esterilização' 'Cirurgia'  
'Medicina Interna 10']  
3.3247863247863254 6  
  
['UCIP' 'Bloco e Anestesia' 'Urgência']  
3.7948717948717956 0  
  
['Neurologia/Pneumologia' 'Internamento' 'Bloco e Anestesia']  
3.034188034188035 9
```

Figure G.2: Example of a Python route output